of

Prepared by
Agricultural
Research
Service

In cooperation with
Cornell University

Agriculture
Information
Bulletin
Number 631

Fire Blight—Its Nature, Prevention, and Control

A Practical Guide to Integrated Disease Management

Abstract

van der Zwet, T., and S. V. Beer. 1991. Fire Blight—Its Nature, Prevention, and Control: A Practical Guide to Integrated Disease Management. U.S. Department of Agriculture, Agriculture Information Bulletin No. 631, 83 pp.

Fire blight is a serious bacterial disease of apples, pears, quinces, and several plants in the rose family (Rosaceae), including hawthorn, cotoneaster, firethorn (pyracantha), mountainash, blackberry, and raspberry. Outbreaks of this disease are usually most severe in areas with a warm, humid climate, especially when these conditions occur during the bloom period of the tree or plant involved. This publication is aimed especially at growers of apples and pears, as many varieties and rootstocks of these fruit are very susceptible to the disease. This bulletin serves as a practical guide for identification of conditions conducive to disease development, identification of symptoms, prevention of disease development, and control of fire blight, including disease prediction. Key references are included for additional information on different aspects of fire blight.

Keywords: *Erwinia amylovora,* fire blight, control, development, prediction, symptoms, integrated orchard management, pome fruits.

While supplies last, single copies of this publication may be obtained, at no cost, on request either from USDA-ARS-NAA, Appalachian Fruit Research Station, 45 Wiltshire Road, Kearneysville, WV 25430, or from Department of Plant Pathology, Cornell University, Ithaca, NY 14853.

Copies of this publication may also be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

Issued September 1992

Acknowledgments

The authors gratefully acknowledge the critical reading and editing of the manuscript and the numerous suggestions for improvement made by the following persons familiar with fire blight: W.G. Bonn, Agriculture Canada, Harrow, Ontario; J.N. Cummins, Department of Pomology and Viticulture, New York State Agriculture Experiment Station, Geneva, NY; C.R. Drake, Department of Plant Pathology, Virginia Polytechnic Institute, Blacksburg, VA; M.A. Ellis, Department of Plant Pathology, Ohio Agricultural Research and Development Center, Wooster, OH; K.D. Hickey, Fruit Research Laboratory, The Pennsylvania State University, Biglerville, PA; P.W. Steiner, Department of Botany, University of Maryland, College Park, MD; S.V. Thomson, Department of Biology, Utah State University, Logan, UT; P.D. VanBuskirk, Jackson County Extension Service, Medford, OR; K.S. Yoder, Fruit Research Laboratory, Virginia Polytechnic Institute, Winchester, VA; W. Zeller, Biologische Bundesanstalt, Heidelberg, Germany; and B.G. Zoller, "The Pear Doctor," Kelseyville, CA.

Contents

Profuse ooze production on young apple fruit in the orchard. (Original photo, courtesy of A.L. Jones, Michigan State University, East Lansing.)

Fire Blight—Its Nature, Prevention, and Control

A Practical Guide to Integrated Disease Management

T. van der Zwet and S. V. Beer

Introduction

Fire blight, caused by the bacterium *Erwinia amylovora* (Burrill) Winslow et al., is a very serious and most perplexing disease of pome fruit. It is most destructive to pears and generally less so to apples and quince. Many ornamental plants in the family Rosaceae are also affected, some quite severely.[30] The name "fire blight" apparently was chosen because affected branches have persistent blackened leaves and the tree or shrub appears as though scorched by fire.

The fire blight organism was apparently indigenous to the State of New York, where the disease was first observed in 1780. At that time, its etiology was unknown, and for a century to follow, the cause of the disorder was variously attributed to lightning, heat scald, frozen sap, insects, human diseases, etc. In 1880, Thomas J. Burrill[7] at the University of Illinois announced that fire blight was caused by a bacterium. In 1884, Joseph C. Arthur[2] at Cornell University presented the first proof, through reinoculation experiments, that a bacterium, now referred to as *Erwinia amylovora,* was the causal agent. During the remaining years of the 19th century, fire blight was responsible for large losses, and these losses prompted a shift of the pear and apple industries westward. They finally settled in the cooler, drier valleys of California and the Pacific Northwest, where initially the disease was less common. Substantial additional pome-fruit acreage, however, is still located in the Northeast, Midwest, and Appalachian region.

---

van der Zwet is a research plant pathologist with USDA-ARS, Appalachian Fruit Research Station, Kearneysville, West Virginia, and Beer is a professor of plant pathology in the Department of Plant Pathology, Cornell University, Ithaca, New York.

Today, fire blight is present throughout North America, including Canada and Mexico, and in numerous other countries of the world (fig. 1). After the disease was first noted in England in 1957, fire blight spread to the coastal regions of The Netherlands in 1965 and has since appeared in all countries of northwestern Europe. In the 1960's the disease appeared on low-chilling pears in the Nile Delta of Egypt; it became very severe in the mid 1980's. During the next 5 years, fire blight spread to Cyprus, Israel, Turkey, Lebanon, Greece, Bulgaria, Yugoslavia, and southern Italy, and presently threatens the commercial fruit industries in the central, southern, and eastern regions of the European Continent. In the Southern Hemisphere, fire blight has been reported only from New Zealand.

Several interesting, more technical reviews on fire blight have been published. [1, 10, 30]

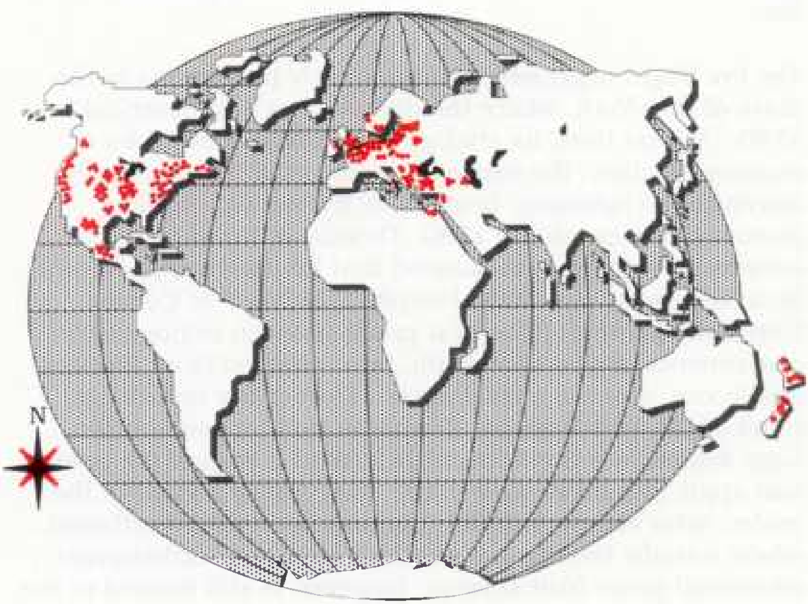


Figure 1. Distribution of fire blight in the world.

Losses

Fire blight not only is destructive to the current year's crops but also reduces subsequent production by killing fruit spurs, branches, and occasionally whole trees. Following a 1982-84 buildup of blossom blight in the Le Conte pear variety in Egypt, crop losses of up to 95 percent were reported for 1985.

In pears and quince, as well as in certain varieties of apple, shoot blight and the blighting of suckers often result in the death of large limbs or even the entire tree. Although still alive, blighted nursery trees are usually unsalable. Infection in the trunk, collar, or roots generally leads to death of the affected trees, and can therefore lead to major losses in commercial orchards. Most of the dwarfing rootstocks used in modern, high-density orchards are very susceptible to fire blight. Rootstock infection may quickly result in the loss of entire trees. Infection of immature fruit or wilting of fruit borne on girdled branches often causes severe crop losses, especially in pear. Progression of fire blight cankers may kill major scaffold limbs of trees, and in the most extreme cases, whole trees may be lost. Such tree loss usually does not occur, except when trees are young (1-4 years) or when older trees are under extremely poor or careless orchard management. Many young trees that have severe blight only in the small branches can be brought back to commercial production over a period of 2-3 years by judicious pruning, spraying, and retraining. Others may be so severely infected throughout, that the most economical course of action would be to remove them and replant. The latter course is probably better with severely blighted trees less than 3 years old.

Accurate estimates of the annual losses from fire blight for given localities or for the Nation as a whole are difficult to obtain. The incidence and severe cases of fire blight are typically very sporadic. With no specific system to measure the devastation caused by fire blight, losses can only be approximated. Estimates in the United States made in the 1950's indicated an annual loss of approximately $4 million, based on the farm value of standard size (nondwarfing) apple and pear trees at that time. The costs of control measures, extended production losses, and tree replacement were not included in this figure. Large losses have occurred in many orchards in various fruit growing areas in different years. Whole blocks of young trees of susceptible varieties must occasionally be removed because of severe fire blight.

In the most recent (1976) survey in 17 States, California reported a loss of $4.7 million, mainly of pear. Among 8 of the 17 bacterial diseases cited in the survey, fire blight was rated of "high importance," and was also recorded as second and/or third most important by plant pathologists in other States. In 1991, a combination of ideal conditions for fire blight development caused extremely severe outbreaks of the disease in southwest Michigan with estimated losses of $3.8 million (fig. 2).

Figure 2. Aerial view of apple orchards in southwest Michigan with extremely severe occurrence of fire blight in 1991. Eight rows of blighted trees on each side of the barns in center are Jonathan and Rome Beauty, whereas nine rows of green trees are Stark Crimson Red Delicious. All trees are on Malling 7 rootstock. (Original photo, courtesy of W.F. Teichman, Eau Claire, MI.)

Symptoms

Symptoms on Fruit Trees

The symptoms of fire blight are easily recognized and, with few exceptions, are readily distinguished from those of other pear and apple diseases. The most obvious symptom on pear *(Pyrus)* or apple *(Malus)* is the scorched appearance of leaves on affected branches. Often, when succulent shoots are affected, they bend characteristically to form the typical "shepherd's crook." Depending on the affected plant part, fire blight may be called blossom blight, shoot or twig blight, leaf blight, fruit blight, limb and trunk blight, or collar and root blight.

Blossom Blight

Blossom blight is usually the first symptom of blight and is found during spring. A single flower or an entire flower cluster may be affected. Blossoms first appear watersoaked; then they wilt, shrivel, and turn brown to black. Infected blossoms may fall, but they usually remain attached as infection kills the abscission layer. The infection progresses into the peduncle (flower stem), which also may appear water-soaked. The peduncle then turns dark green and, finally, brown or black. During warm, humid weather, droplets of bacterial ooze often exude from the peduncle (plate (pl.) 1, A). Following blossom infection, young fruit often become infected through internal invasion from the fruit spur. Fruit turn black, appear dried and shriveled, and usually remain attached.

Blossom infection usually leads to the invasion of the neighboring spur leaves through the petiole and then the midrib and main veins. Some fruit of a diseased cluster may at first escape infection but later become infected through the peduncle from the affected cluster base (pl. 1, B). Single blossom infections often lead to the loss of entire spurs. Sometimes blossoms located on a fruit spur of a trunk or main branch become infected, and the infected blossoms may lead to an infection that girdles the whole branch or tree (pl. 1, C). Such girdling occurs more frequently on dwarf or trellis-trained trees.

A

B

Plate 1

A. Small clear ooze droplets on green flower stem, depicting the earliest symptom of blossom blight on apple.
B. Advanced blight on pear blossoms and young fruits.

Shoot Blight

After blossoms, succulent shoots and water sprouts or suckers are the most susceptible to infection. During some seasons, shoot (or twig) blight may be the only symptom observed. Shoot symptoms are similar to those found in blossoms, except that infection usually progresses more rapidly, especially under weather conditions (described later) that are optimum for blight development. In a few days, infection can move 15-30 cm (6-12 inches) or more into the shoot. Infected shoots, bark, and leaves usually turn light to dark brown in apples (pl. 1, D) and dark brown to black in pears (pl. 1, E).

Blighted terminal shoots and water sprouts often form a shepherd's crook at their tips (pl. 1, F). During moist conditions, drops of bacterial ooze frequently appear on the blighted shoots. Twig blight may also result from girdling below the shoot tip, following invasion through the spurs or previously blighted twigs or leaves. Numerous blighted twigs with attached dead leaves appear as though scorched by fire.

Leaf Blight

Leaves may become infected after bacteria enter directly through the stomata (leaf openings) or, more frequently, through wounds caused by insects, hail, and wind whipping. If infection occurs in the lamina (leaf blade), a necrotic section appears. This part of the leaf may dry, but infection frequently spreads through the secondary veins into the midrib; then into the petiole (leaf stem) and the supporting stem. Characteristic blackening of the petiole and leaf midrib often occurs and ooze drops are frequent (pl. 1, F). In some infected leaves, only a small necrotic part extends inward from the margin 0.6-1.2 cm (1/4-1/2 inch); in others the affected area includes the midrib, and in still others the entire leaf becomes necrotic. Under some weather conditions, bacterial strands (fine threadlike structures composed of bacterial cells embedded end to end in a matrix) are produced on leaf petioles and shoot tips (pl. 1, G).

C

D

E

Plate 1

C. Infection of fruit spur from extending canker on apple trunk resulting in canker blight.

D. Twig blight on apple, showing characteristic light-to dark-brown leaves adhering to branches.

E. Severe twig blight on pear, with characteristic dark brown to black leaves attached to branches.

F

G

Plate 1

F. Symptom of shoot blight on Bartlett pear, characterized by shepherd's crook and profuse oozing from purplish, succulent shoot tissue.

G. Characteristic blackening of leaf midrib and presence of bacterial strands of *Erwinia amylovora* around leaf petioles and young pear shoot.

Fruit Blight

Immature fruit may become infected through lenticels (natural openings) in the skin, through wounds, or from an infected spur. Fruit infection is most common following summer hailstorms. The infected part of the fruit may at first appear gray green or water-soaked; later it becomes brown to black. Infected pears nearing maturity often show a dark-green, water-soaked edge along the infected area (pl. 2, A), whereas apples exhibit a premature reddening of the area bordering the infection (pl. 2, B). A sticky, milky to amber-colored fluid sometimes oozes from the lenticels. A green, blighted pear may produce abundant bacteria (pl. 2, C). In arid (low humidity) regions, masses of bacterial tendrils or strands have been observed on apples (pl. 2, D) and on pears (pl. 2, E and F). Infected apple and pear fruits turn brown and black, respectively, shrivel, and appear mummified as they remain attached to the spur.

A

Plate 2

A. Typical advanced blight in Moonglow pear fruit, characterized by water-soaked margin and green ring along border of blackened necrotic area.

B

C

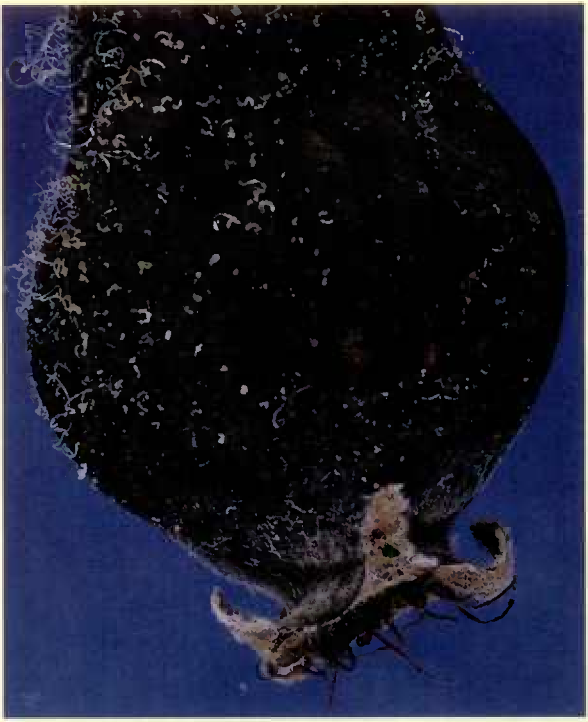
Plate 2

B. Advanced blight in Jonathan apple fruit, showing characteristic red margin along blotchy necrotic area; note ooze droplet on left side of fruit.

C. Numerous clear droplets of bacterial ooze clinging to necrotic area of blighted pear fruit.

D

Plate 2
D. Small bacterial tendrils forming from lenticels of Rome Beauty apple.



E

F

Plate 2

E. Masses of bacterial strands on pear fruit.
F. Close-up view of bacterial strands in pl. 2, E.

Limb and Trunk Blight

In the more disease-susceptible hosts, infections may advance downward from the blossoms, shoots, or fruit through the larger twigs and older branches toward the trunk. The infection may continue into scaffold limbs of the main body of the tree. Abundant ooze, which flows along the bark, often accompanies the development of infection (pl. 3, A). Flies are often attracted to the ooze and may spread the bacterium (pl. 3, B).

Fire blight in the main part of a tree trunk is often called trunk or body blight. One of its earliest signs is the presence

A

Plate 3

A. Characteristic brown streaking on central leader of very susceptible pear tree, resulting from profuse production of bacterial ooze and tree sap.

of amber-colored ooze drops and plant sap running along the bark (pl. 3, C), together sometimes with the presence of small cracks in the bark tissue. In trees with trunks especially susceptible to *E. amylovora*, such as the Magness pear variety, infection may spread from the trunk into scaffold limbs within a few months, frequently killing the tree. Often, diseased Magness bark appears a distinctive purple, which aids in identifying fire blight in this variety.

Renewal of bacterial activity in spring at the margins of indeterminant cankers (i.e., cankers without pronounced margins) results in extension of the cankers. Infections can spread into adjacent water sprouts, shoots, and limbs, and such an extension of cankers today is called canker blight. Canker extension may begin before, during, or shortly after bloom, depending on spring orchard temperatures (see MARYBLYT prediction model). Thus, in some years, the bacterial ooze produced as a consequence of canker extension may serve as the earliest inoculum for the season. Canker extension often is responsible for considerable loss of tree structure.

B

Plate 3

B. Flies visiting sticky, moist canker surface.

Collar and Root Blight

Collar and root blight can be most destructive and frequently kills trees. Collar, or crown blight, affects the base, or ground level, of the tree trunk (pl. 3, D). Infection may spread from the collar into the roots or sometimes from the roots into the collar. Infection in the collar can be initiated through burr knots or through wounds created by woolly aphids or other factors on root or trunk sprouts. Infections in the base of the trunk often appear dark, water-soaked, and purplish. Their margins are indefinite or raised and blistered at first but become definite and marked by a crack or crevice later (pl. 3, E). Upon removal of the bark, the affected area may show red-brown streaking in the internal tissues (pl. 3, F). Collar blight may occur in trees that show no other evidence of infection and may be easily confused with other root and collar diseases.

Bark on the roots is killed in much the same manner as that on the trunk. Invasion of the crown and roots may occur in one of several ways: 1) through infected suckers or water sprouts, 2) washing of bacteria from infected twigs and fruit down the trunk and into the soil containing the roots, and 3) internal translocation of fire blight bacteria from infected plant parts above ground to the rootstock. During the past 15 years, considerable collar and root blight has been found in the susceptible Malling (M.9 and M.26) dwarfing apple rootstocks. Occasionally, poor growth of apple and pear trees has been associated with fire blight infection in their root system. When a trunk canker develops near the collar and reaches the border of a resistant rootstock or interstem, a distinct margin between diseased and healthy tissue is often observed (pl. 3, G).

C

D

Plate 3

C. Early sign of bacterial ooze on tree trunk of apple.

D. Characteristic purple coloration of fire blight in the apple scion trunk just above the union with M.26 rootstock.

E

F

G

Plate 3

E. Symptom of collar blight in trunk base of apple tree,

F. Typical red-brown streaking in cankered area after bark is removed.

G. Characteristic brown coloration in infected scion portion of apple tree, with line of demarcation (graft line) between diseased scion and healthy rootstock.

Symptoms on Ornamental Plants

Symptoms of fire blight on quince *(Cydonia)*, crabapple *(Malus)*, and other ornamental trees and shrubs are generally similar to those described for apple and pear. Dead leaves cling to their shoots on most host plants. On infected quince, the leaves become characteristically tan to light brown (pl. 4, A). Freshly blighted shoots on crabapple, hawthorn *(Crataegus)*, cotoneaster *(Cotoneaster)*, and firethorn *(Pyracantha)* later often produce characteristic ooze drops on older wood. Infected hawthorn shoots typically display blighted blossom clusters and characteristically purple surfaces of cankers (pl. 4, B and C). Infected succu-

A

Plate 4

A. Characteristic light-brown to tan leaves of blighted quince.

B

C

Plate 4

B. Early symptoms of blossom blight on hawthorn.

C. Characteristic brown leaves of advanced blossom blight on English hawthorn.

lent shoots of pyracantha and cotoneaster often display a characteristic shepherd's crook (pl. 4, D and E). In hawthorn shoots, care must be taken not to confuse fire blight symptoms with similar symptoms caused by Monilinia canker (a fungal disease), salt-wind injury (near open seas), or severe winter damage. Bacterial strands have also been observed on hawthorn. On stranvaesia *(Photinia*, formerly *Stranvaesia)* shrubs, the most characteristic symptom is the drooping of affected terminal blossom clusters, the leaves of which become light brown underneath (pl. 4, F).

D

Plate 4

D. Twig blight in young pyracantha shoot, showing characteristic red-brown leaves and typical curving of shoot tip.

E

F

Plate 4

E. Typical shepherd's crook symptom on cotoneaster shoots, with medium-brown leaves and dark midribs.

F. Blighted blossom cluster, with light-brown leaves on stranvaesia shrub.

A

Plate 5

A. Characteristic symptom of blossom blast on pear, caused by *Pseudomonas syringae*, showing shriveled up infected blossoms.

Other Disorders With Symptoms That Resemble Fire Blight

Several diseases and insect pests cause pear and apple trees to show symptoms that closely resemble those of fire blight.

Pear Blast

Pear blast, caused by the bacterium *Pseudomonas syringae* pv. *syringae*, is often confused with fire blight. In the orchard, the symptoms of affected blossoms and young shoots are sometimes indistinguishable from those due to fire blight (pl. 5, A). Ooze associated with pear blast is less abundant, darker, and more transparent than that associated with fire blight. Blossom infections usually occur in cool wet weather, and shoot infections rarely extend into large scaffold limbs. Late in the growing season, pear blast in young shoots can be recognized by the following symptoms: 1) A sharp margin between the living and necrotic portions of the shoot, 2) peeling of the outer bark at the base of the blighted shoot, and 3) absence of a shepherd's crook at the shoot tip. Leaf and fruit infections appear as dry localized lesions. Pear blast is most damaging to blossoms, and losses of limbs and branches rarely occur.

Nectria Twig Blight

Certain fungal diseases cause symptoms that closely resemble those of fire blight, especially on blossoms and young shoots. The most common is Nectria twig blight or dieback, caused by *Nectria cinnabarina*. This disease is especially prevalent on the Rome Beauty apple variety. Infection is initiated in late fall but develops more extensively at the base of diseased twigs in the following summer. From a distance, blighted branches appear similar to those affected by fire blight (pl. 5, B). On close examination, however,

B

Plate 5

B. Twig blight symptom on Rome Beauty apple, caused by *Nectria cinnabarina*.

Nectria twig blight may be distinguished by the characteristic bright-orange fungal fruiting structures on the canker surface (pl. 5, C). A European canker or limb canker, caused by *Nectria galligena*, is a similar disease. It is characterized by a series of callus folds surrounding a central canker cavity which extends to the wood. These cankers, however, are usually centered around bud scars, wounds, and twig stubs or are started in limb crotches.

C

Plate 5

C. Close-up of characteristic orange-red-tinted base of *Nectria* canker in pl. 5, B.

European Pear Dieback

On blossoms and twigs, the symptoms of European pear dieback, caused by *Phomopsis tanakae*, closely resemble those of fire blight (pl. 5, D). A similar pear dieback, caused by a *Phomopsis* species endemic in Japan, is not present in America. Both fungal pathogens produce stringlike masses of fungal spores on stem cankers, which appear much like the bacterial strands of *E. amylovora*. Except when blossoms and shoots are in the early stages of infection by European pear dieback, close examination of the affected tissues and their symptoms will usually allow the disease to be distinguished from fire blight.

D

Plate 5

D. Wilting of pear blossoms (European pear die-back) caused by *Phomopsis tanakae*. Note lack of black coloration in blossoms. (From T. Sakuma and H. Miyagawa, 1981. "Studies on European Pear Dieback Renamed. I. Symptoms and Its Causal Agent." Bulletin of the Tree Fruit Research Station. Series C, No. 8: 67-76. Reprinted by permission. Original photo, courtesy L.R. Batra, USDA, ARS, Beltsville, MD.

Twig Borer Beetle

One insect pest causes blightlike symptoms in young pear shoots. The branch and twig borer beetle, *Polycaon confertus*, is occasionally found in pears, but infestation seldom reaches damaging proportions. The adult beetles bore into small young shoots, usually at the axil of a bud or fruit spur. From a distance, dying shoots closely resemble shoots damaged by fire blight (pl. 5, E). However, a distinguishing characteristic of the beetle damage is that the petioles with drooping leaves do not discolor.

E

Plate 5

E. Blightlike shoot damage caused by twig borer *(Polycaon confertus)* burrowing in branch at base of pear shoot, resulting in typical purplish-black coloration of succulent shoot but not of leaf petioles. (From Ethell and Barnett, 1978. "Pear Pest Management." University of California, Richmond, CA. Preprinted by permission. Original photo, courtesy R.S. Bethell and W.W. Barnett, University of California, Davis.)

Disease Cycle

The development of fire blight disease follows the seasonal development of the host plant closely and hence appears cyclic in nature. Therefore, it is convenient to consider the cycle as beginning in the spring with the production of primary inoculum and the infection of blossoms, continuing through the summer with the infection of shoots and/or fruits, and ending in late summer or early fall with the development of cankers. Because cankers develop when infection slows, they may appear in late spring, summer, or fall (fig. 3). The pathogen appears quiescent through the dormant period of the host.

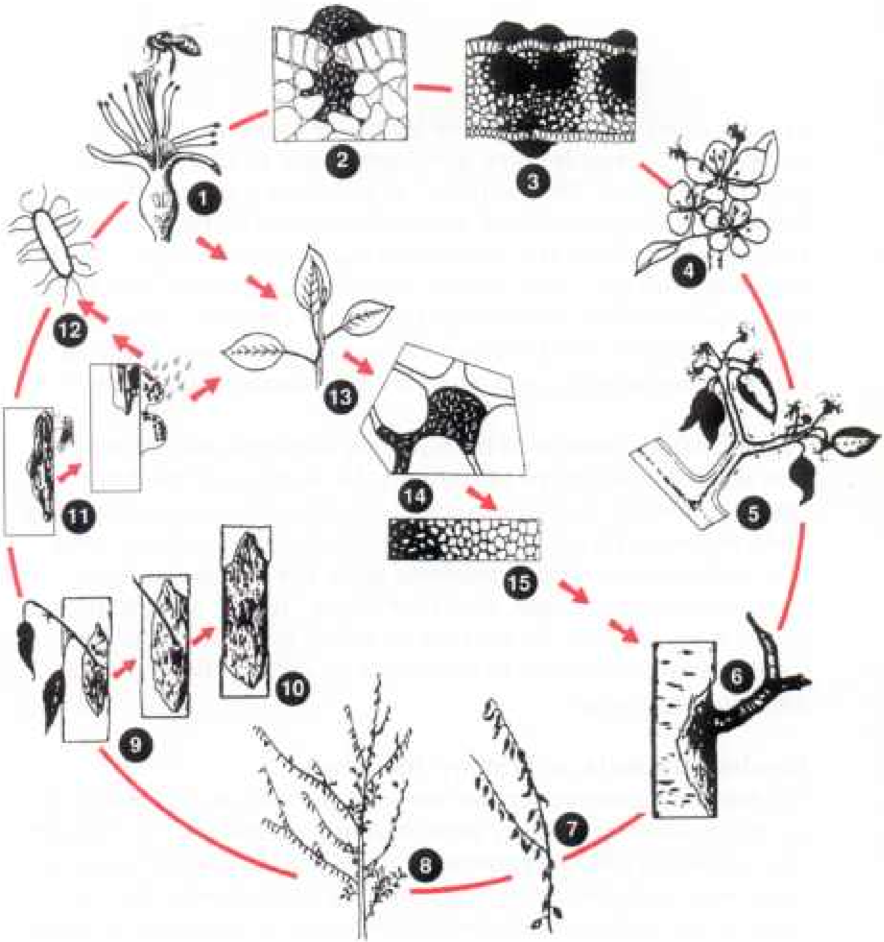
Primary Infection

The primary infection (i.e., the first infection of the season) by fire blight occurs in the spring when the bacteria invade the blossoms or shoots of the host plant. The origin of these bacteria may be the previous year's cankers that became active in early spring of the current year and/or the "resident" bacteria, present as epiphytic (on the surface) and/or the endophytic (internal) microorganisms, on or inside the tree tissues.[31]

Growing mainly the most resistant varieties of fruit trees and ornamental plants will keep nursery costs for fire blight to a minimum.

Production of Primary Inoculum by Holdover Cankers

Fire blight cankers can vary in diameter from 3 to 8 mm (0.1 to 0.3 inches) in the current season's shoots, to 15 to 20 cm (6 to 8 inches) or larger on limbs and tree trunks. In the spring, a small percentage of cankers formed in the previous year become active as sources of primary inoculum—cells of *Erwinia amylovora* that will serve to initiate the first new infections of the season. Such cankers are referred to as "holdover cankers." Cankers located on larger limbs or branches and those with margins that are not pronounced



1. Bees carry bacteria from flower to flower.
2. Bacteria penetrate flowers through wounds or stomates.
3. Bacteria multiply and spread intercellularly.
4. Infected blossoms shrivel and die.
5. Infection spreads to other blossoms, fruits, twigs, and leaves.
6. Formation of new cankers on branches and stems.
7. Twig killed by fire blight with dead leaves clinging to stem.
8. Young tree severely blighted.
9. Bacteria overwinter at margins of old cankers.
10. Cankers enlarge, girdle branch or stem and produce ooze.
11. Bacteria in exudate are disseminated by crawling and flying insects and by rain.
12. The fire blight bacterium.
13. Direct infection of young twigs.
14. Intercellular multiplication and spread of bacteria in bark tissues.
15. Cells of infected bark tissue collapse.

Figure 3. Disease cycle of fire blight. (From S.V. Beer, 1976. "Fire Blight: Its Nature and Control." Cornell University Information Bulletin 100.)

are the most likely to become holdover cankers. Such cankers will usually have developed later in the previous growing season. The "activity" of holdover cankers results from the multiplication of *E. amylovora* in the healthy bark tissues adjacent to the overwintering canker margin. As the bacteria multiply, they invade healthy bark tissue and often cause substantial additional damage to the tree. The extension of holdover cankers can cause serious losses early in the growing season, and provides for primary infections.[4]

The inoculum produced by holdover cankers may be invisible or visible as drops of ooze on the surface of the bark (pl. 3, A and C). Large numbers of cells of *E. amylovora* have been recovered from the surfaces of holdover cankers without visible ooze. Viable bacteria have been isolated from cankers on pear, apple, and hawthorn. In the spring, fire blight bacteria may be carried by wind, rain, and insects from holdover cankers to blossoms or young shoots, where infection may start.

Resident Bacteria as Primary Inoculum

Erwinia amylovora may live for long periods as a resident in or on apparently healthy pear and apple tissues, i.e., tissues that show no blight symptoms.[5,12,20,31] Endophytic bacteria have been isolated from symptomless side shoots that develop from axillary buds below the bases of cankers on apple and pear trees in the greenhouse and from suckers on blighted Bartlett trees in the field. Endophytic bacteria were also isolated from dormant branches of three other *Pyrus communis* varieties which had no record of visible fire blight. Resident epiphytic populations of *E. amylovora* on shoots, leaves, and buds were not reported until the early 1970's. Studies using scanning electron microscopy and photography have since revealed the presence of *E. amylovora* on surfaces of apparently healthy blossoms (fig. 4) and internal tissues of pear and apple (fig. 5).

Research in California showed that *E. amylovora* can live as an epiphyte on flowers, fruits, and leaves of apparently healthy pear trees, on the surfaces of cankers that do not appear to be extending, and even on some local weeds.

Figure 4. Epiphytic bacterial cells on the surfaces of the pistil of a Bartlett pear flower (X 5,000). (Original photo, courtesy S.V. Thomson, Utah State University, Logan.)

Figure 5. Endophytic bacterial cells in the xylem vessel of an apple shoot (X 2,650). (Original photo, courtesy R.N. Goodman, University of Missouri, Columbia.)

Epiphytic populations varied among orchards and trees and were detected from 2 to 4 weeks before the appearance of any blight symptoms. This information may explain the occurrence of blight epidemics in orchards in which holdover cankers had not been detected.

Blossom Infection

Primary infection usually takes place in blossoms and develops into blossom blight. In some years, however, primary infection involves shoots rather than blossoms. Primary inoculum originates within or near the orchard from holdover cankers or from bacteria in or on developing buds. Wind and rain, together with warm, humid weather during bloom, favor the development of severe blossom blight. Once deposited in an open blossom in warm weather, the bacteria multiply in the nectar or on the stigmatic surfaces of the flower. It has been reported that during dry weather, the nectar in blossoms may become too concentrated for bacterial growth but that rain or heavy dew may dilute the nectar, enabling the bacteria to multiply and provide abundant inoculum.

The bacteria can enter unwounded blossoms through natural openings and have been reported to move through specialized nectar-secreting stomata of the flower's nectary, uncutinized stigmas, undehisced anthers, as well as stomata on the sepals.[11] The bacteria multiply and advance into the intercellular spaces. Small ooze droplets on the flower stems and darkened sepals are the earliest symptoms to be observed (pl. 1, A). After a few days, plant cells die and marked necrosis is apparent. Sometimes, only one or two flowers in a cluster are blighted initially. Often, however, infection of even one flower leads to death of all blossoms in the cluster. In pear flowers, invasion generally occurs more rapidly through nectaries and pistils, whereas in apple flowers the stigmas and the anthers are invaded first. The morphological differences of open receptacles in pears versus closed receptacles in apples appear to account for this variation.[20,21]

Even before infection is obvious, the bacteria from one blossom can be transferred to many others by rain or by pollinating insects, especially honey bees. Insects that visit infested blossoms pick up the bacteria on their bodies and may transfer them to many other blossoms. This cycle can be repeated as long as open blossoms are present and may result in a large number of blossoms being colonized well before environmental conditions supporting infection actually occur, if they occur at all. In orchards where secondary (rattail) bloom occurs, dissemination and continuous infection may continue for months. Once a new supply of bacteria (ooze) is present in the orchard (pl. 1, B and F), fire blight becomes very difficult to control.

Flower colonization by the pathogen flourishes under the same conditions that favor bee activity—warm temperatures, sunshine, and still air. Insect dissemination is not exclusive to honey bees; other insects that visit blossoms can be effective disseminating agents. Since honey bees generally work along a row of trees in high-density apple plantings, inoculation by honey bees is likely to result in patches of fire blight within rows. Dissemination of inoculum by rain is likely to be of greater importance when bee activity is not favored, is likely to involve shorter distances than that by bees, and usually involves blossoms or shoots near holdover cankers.

Although the mechanism by which *E. amylovora* kills plant cells is not known, infection clearly results in the breakdown of the plant cell membranes, perhaps due to the action of a toxin produced by the bacteria. After killing the initial blossom, *E. amylovora* may progress into the flower stem and spur, and finally the supporting branch. If the infection girdles the branch, all plant tissues from the girdled site to the outermost tip of the branch will be killed. The extension of infection may cease at any time, as a result of weather and host-specific factors. At that time a canker forms.

Shortly after full bloom, primary infection may continue in rattail blooms in certain varieties or geographic locations. Also, leaves and tender succulent shoots may be invaded early in the season. Insects or rain may deposit the fire blight organism on the surfaces of these tissues, or insects may introduce the bacteria into the host tissues during feeding. In California, shoot infections have often been observed in apple orchards that had had little or no blossom infection. In those situations, insect vectors are likely to have introduced the pathogen from other nearby sources.

Secondary Infection

Once primary infection has occurred and the pathogen advances through the tissues, secondary infections may be initiated throughout the growing season. Inoculum may originate as bacterial ooze or strands produced on shoots, leaves, fruit, or larger branches. Once immature fruit become infected, they can produce an enormous amount of inoculum for repeated secondary infections (pl. 2, A, B, D, and E). The bacteria can be disseminated by rain, wind, insects, or birds, or by humans using contaminated pruning tools. Secondary infections are usually more numerous than primary ones and generally cause more serious injury to the trees. Also, they can be quite severe toward the end of the growing season. Such severe secondary infections are usually associated with a late flush of shoot growth, due to excessive rainfall, plus a buildup of aphid populations (pl. 6, A).

Fire blight bacteria may enter leaves and succulent shoots directly or through wounds. Numerous experiments and field observations have indicated the importance of wounds as avenues for bacterial entry into the host.[29] Types of injuries vary from small insect punctures and stem abrasions to large wounds caused by severe wind, hail, or frost. Young pear and apple fruits are especially susceptible to infection after hailstorms.

Sucking insects, particularly aphids, plant bugs, and pear psylla, are instrumental in initiating infections in vegetative shoots and especially root suckers. These insects tend to feed on soft, succulent shoots—the same shoots that are highly susceptible to fire bight infection. During feeding, the insects not only create wounds that may facilitate entry of the pathogen into host tissue but also may carry the pathogen from an infected shoot to an uninfected shoot.

A

Plate 6

A. Severe late-season (August-September) shoot blight in 30-year-old Rome Beauty apple trees following excessive rainfall and heavy buildup of apple aphids.

Canker Formation

Toward the end of the growing season, or in some situations much earlier, multiplication of the bacteria slows down and cankers are initiated. The bacteria remain abundant at the advancing edge of infection, but as soon as the bark tissues die, most of the bacteria die also.

Cankers develop in the bark when the progress of the infection slows. They may be slightly sunken, may vary in size, and are usually surrounded by irregular cracks in the bark (pl. 6, B and C). At first, the margin may be indefinite or indeterminant (pl. 3, C), raised, or blistered. Later many cankers develop a definite crevice or crack, and such cankers are described as determinant cankers (pl. 6, B). The actual canker consists mainly of dead and collapsed bark cortex and phloem tissues. Internally, a distinct barrier zone exists between the healthy and infected wood (pl. 6, D), and the infected tissue is usually totally devoid of starch, as shown by the lack of blue coloration in a starch-iodine test (pl. 6, E). Cankers formed at the base of blighted fruit spurs (pl. 1, C), water sprouts, limbs, branches, or trunks are the main overwintering sites for the fire blight pathogen. The bacteria usually live in healthy tissue in the area immediately adjacent to the edge of the visible canker.

In spring, some cankers become active and have a dark, water-soaked appearance. When the bark is peeled or cut away from the infected limb or twig, characteristic red-brown streaks are often found in the sapwood (pl. 6, F). If plant growth continues after infections cease to extend, the bark tissues killed by *E. amylovora* are walled off by periderm formation. Sometimes brown streaks may be found in the live bark tissue beyond the crevice. Occasionally, these streaks progress downward through the bud-leaf gap parenchyma tissue into the pith of young shoots, and late infections may appear 10 to 25 nodes below the lesion margin. In these tissues the bacteria may be abundant throughout the following winter and spring.

B C

Plate 6

B. Advanced canker in central leader of young pear tree, showing typical cracking along upper margin of cankered area; note characteristic blackening toward base of canker and dark-brown clinging leaves.

C. Several young cankers on branch of Golden Delicious apple tree, with characteristic orange-brown discoloration within cankered area; infection apparently started in young shoots and spread into main limb.

D

E

F

Plate 6

D. Longitudinal section through pear branch showing the planar surface of the branch interior and a distinct barrier zone between edge of determinant canker and healthy wood tissue.
E. Section through York apple branch showing total depletion of starch (absence of blue color in starch-iodine test) in cankered area.
F. Characteristic red-brown streaking below the bark of a canker in spring.

Factors Affecting Disease Development

The development of fire blight depends on the interaction between the host and the pathogen as mediated by the environment, which includes weather and insects. Both the quantity (amount) and quality (virulence) of the pathogen are important. Host susceptibility depends on the location of the orchard, soil conditions, tree nutrition, and cultural practices in the orchard. Environmental conditions may affect the pathogen, the host, or their interaction during the growing season. For maximum development of fire blight, specific conditions for each of these three factors must be optimal concurrently.

The Host

Plant Resistance

Fire blight has been reported on approximately 200 plant species in 40 genera of the Rosaceae family.[30] Plants in the following eight genera are the most familiar or important commercially to fruit growers, nurseries, and landscapers:

Cotoneaster (cotoneaster)	*Malus* (apple)	*Photinia* (stranvaesia)
Crataegus (hawthorn)	*Pyrus* (pear)	*Pyracantha* (firethorn)
Cydonia (quince)		*Sorbus* (mountainash)

Fire blight is generally the most destructive to the dessert pear *(Pyrus communis)*. Pear varieties with the most desirable fruit texture and flavor are generally the most susceptible to infection and destruction. However, this relationship does not hold for all commercial apple varieties *(Malus domestica)*. Historically, fire blight has been more destructive to pears, but apples in the East and Midwest of the United States have been affected seriously. The relative orders of resistance to fire blight among the most common apple and pear varieties and rootstocks are listed in tables 1, 2, and 3. However, the inherent resistance of plants is influenced strongly by the conditions under which they are grown. Ratings of the traits of pear and apple rootstocks in regard to soil tolerance, horticultural characteristics, and resistance to diseases, nematodes, and insects are presented in tables 4 and 5, respectively.

Table 1. Relative fire blight resistance of apple varieties and rootstocks in North America

Host	Most	Moderately	Least
Dessert apple	Arkansas Black Delicious Liberty Northwestern Greening Priam Prima Priscilla Quinte Redfree Sir Prize Winesap	Baldwin Ben Davis Empire Golden Delicious Granny Smith Gravenstein Grimes Golden Jerseymac Jonafree Jonagold Jonamac Macoun McIntosh Monroe Mutsu Northern Spy Spartan Stayman Summer Rambo	Beacon Braeburn Burgundy Cortland Fuji Gala Idared Jonathan Lodi Molly's Delicious Niagara Nittany Paulared R.I. Greening Rome Beauty Twenty Ounce Tydeman Early Wayne Wealthy Winter Banana Yellow Newton Yellow Trans-parent York Imperial
Crab-apple	Adirondack Ames White Centurion Harvest Gold Naragansett Profusion White Cascade Whitney	Bob White Centennial Dolgo Florence Ormiston Roy Red Splendor Spring Snow Winter Cold	Hyslop Marshall Slender Pink Perfection Silver Moon Snowdrift Transcendent White Candle
Rootstock	M.7 Novole Robusta 5	Bemali MM.106 MM.111 Ottawa 3	Alnarp 2 C.6 (interstem) M.9 M.9 (interstem) M.26 M.27 Mark

Table 2. Relative fire blight resistance of pear varieties and rootstocks in North America

Host	Most	Moderately	Least
Dessert pear	Ayers Harrow Delight Harvest Queen Honeysweet Magness Maxine (Starking Delicious) Monterey Moonglow Tyson	Dawn Douglas Duchesse d'Angouleme Garber Lincoln Luscious Rogue Red Seckel Spartlett Worden Seckel	Aurora Bartlett (Williams)[1] Beurre Bosc Beurre d'Anjou[1] Beurre Hardy California Cascade Clapp's Favorite[1] DeVoe Doyenne du Comice[1] Earlibrite Flemish Beauty Forelle Gorham Highland Packham's Triumph Sierra Starkrimson (Red Clapp) Winter Cole Winter Nelis
Asian pear	Seuri Shinko Singo	Ar-riang one Chojuro Imamura aki Ishiiwase Kosui Kumoi (New Century) Shinsui Tsu Li	Hosui Ichiban nashi Kikusui Meigetsu Niitaka Nijisseiki (20th Century) Okusankichi Shinseiki Seigyoku Ya Li
Low chilling pear	Flordahome Hood Pineapple Tenn	Baldwin Carnes Kieffer Orient	Le Conte

Table 2. continued

Host	Most	Moderately	Least
Ornamental pear	Autumn Blaze Bradford Capital Chanticleer Whitehouse		
Rootstock	Old Home (OH) OH x Farmingdale (OHF) (except OHF 51) *P. calleryana* *P. betulaefolia* seedlings[2]	*P. betulaefolia* seedlings	Bartlett seedlings Provence quince Quince A and C Winter Nelis seedlings

[1] Including red sports.

[2] Selections from Reimer(19).

Table 3. Relative fire blight resistance of pear and apple varieties in Europe[1]

Host	Most	Moderately	Least
Dessert pear	Alexander Lucas	Beurre d'Amanlis	Abate Fetel
	Beurre Giffard	Beurre Diel	Alexandrine Douillard
		Beurre Hardenport	Beurre Clairgeau
		Bonne Louise d'Avranches	Beurre Durondeau
		Butirra Precoce Morettini	Blanquilla
		Charneu	Bristol Cross
		Conference	Bunte Juli
		Kaiser Alexander	Concorde
		Pierre Corneille	Comtessa de Paris
			Cure
			General Leclerc
			Grand Champion
			Jules Guyot
			Laxton's Superb
			Passe Crassane
			Precoce de Trevoux
			Triomph de Vienne
Perry pear	Brown Bess	Brandy	Barnet
	Green Horse	Hendre Huffcap	Blakeney Red
	Hellen's Early	Winnals's Longdon	Butt
	Red Longdon		Geisshirtle
	Rock		Gelbmostler
	Schweizer Wasserbirne		Gin
	Taynton Squash		Judge Amphlett
	Thorn		Mollebusch
	Yellow Huffcap		Moorcroft
			Oldfield
Dessert apple	Boskoop	Alkmene	Abbondanza
	Glockenapfel	Elstar	Berlepsch
	Jamba	Fiesta	Cox's Orange Pippin
	Jugol	Melrose	Herzogin Elsa
	Maigold	Oldenburg	Gloster
	Mantet	Royal Gala	Goldparmane
	Nova		Ingrid Marie
	Ontario		James Grieve
			Klarapfel
			Morgenduft
			Tydeman's Early

Table 3. continued

Host	Most	Moderately	Least
Cider apple	Bohnapfel Bulmer's Norman Coat Jersey Dabinett Dunkerton's Sweet Improved Dove Stoke Red Sweet Coppin Taylor's Sweet	Bitterfelder Engelsberger Harry Master's Jersey Hauxapfel Michelin Nehou Somerset Redstreak Tremlett's Bitter	Avroll Breakwell's seedling Brown Snout Chisel Jersey Stembridge Jersey Vilberie Yarlington Mill

[1]Other varieties also grown in Europe are listed in table 1.

Table 4. Ratings of pear rootstock characteristics[1]

Rootstocks	Tolerance to— Low pH	High pH	Water logging	Drought	Tree vigor
Bartlett sdlg.	3	2	4	3	4
Nelis sdlg.	3	2	4	3	4
French sdlg.	3	2	4	3	4
Bartlett clone	3	2	4	3	3
Old Home clone	3	2	4	3	5
OH × F clones	3	2	3	3	2-4
P. calleryana sdlg.	4	2	4	5	4
P. betulaefolia sdlg.	3	2	5	5	5
Provence quince	3	1	3	2	2
EM quince A	3	1	3	2	2
EMLA quince C	3	1	3	2	2

Sdlg. = seedling

[1]Rating: 0 = none, not tolerant, not resistant; 3 = slight, moderately resistant; 5 = much, high, very tolerant, or resistant.

From Westwood and Lombard[32], Department of Horticulture, Oregon State University, Corvallis.

				Resistance to—		
Root sprouts	Hardiness	Yield efficiency	Graft compatibility	Pear decline	Root aphid	Nematodes
2	4	4	5	4	0	1
2	4	4	5	4	0	1
3	4	3	5	3	0	1
0	4	4	5	5	0	1
4	4	2	5	5	0	1
1	4	4	5	5	1	1
1	2	4	5	4	5	5
0	3	4	5	5	5	1
2	2	5	5	5	5	5
2	2	5	5	5	5	5
2	2	5	5	5	5	5

Table 5. Ratings of apple rootstock characteristics for trees of different sizes[1,2]

Rootstocks	Tolerance to— Water logging	Tolerance to— Drought	Precocity	Productivity
Highly vigorous (110% to 90% of standard)				
Domestic seedling	3	4-	2	1
Novole	3	4	4	4
Medium vigor range (85% to 60% of standard)				
MM.106	2	3	5	5
MM.111	3	4	3	4
Alnarp [2]	3	3	4	4
Half size and smaller				
M.7	3	5-	4+	4
M.9	3	2	5+	5+
M.26[3]	2	1	5	5

[1]Rating: 0 = unacceptable; 3 = acceptable; 5 = excellent.
[2]Tree size expressed as percentage of standard size, half size, and smaller.
[3]Stock not evaluated under New York conditions extensively enough to permit recommendations.

From Cummins and Norton[(8)], Department of Pomology, N.Y. Agricultural Experiment Station, Geneva, N.Y.

Hardiness	Anchorage	*Resistance to—* Collar rot	Wooly aphid
3	5	3-	2
3	5	5	3
3	4	2	4
4	4	4	4
5	5	4	2
4	3-	4-	2
3	1	5+	1
4	2	3	0

Choosing resistant fruit varieties, rootstocks, and interstems must be the first priority in preventing or controlling fire blight.

Other fruit crops which have occasionally shown moderate to severe damage to fire blight are thornless blackberries in Maryland, Illinois, and Wisconsin and raspberries in Maine, North Carolina, Wisconsin, and Alberta. In blackberries, the varieties Thornfree, Black Satin, Smoothstem, and Dirksen Thornless are very susceptible to fruit blight (pl. 7, A), and infections can also appear at axillary buds, causing girdling of the canes. In red raspberries, the varieties Latham and Boyne are reportedly quite susceptible to blossom blight, and in some instances entire canes may be killed (pl. 7, B). Minor occurrences of fire blight have been reported on loquat, medlar (mespil), strawberry, and all members of the stone fruits.

Among ornamental plants, certain varieties of cotoneaster, hawthorn, pyracantha, and mountainash are extremely susceptible to fire blight. The relative orders of resistance of the more common commercial species and some varieties of ornamental rosaceous plants are listed in table 6.

Plant Organs and Age

Fire blight infection may be initiated in blossoms, foliage, succulent stems, or fruit. Initiation of blossom infection does not require wounds. Thus, other factors being equal, infection is more likely to be initiated during bloom than at other times. Consequently, the control program in many geographical areas is directed toward minimizing the occurrence of blossom blight. Rapidly growing, succulent shoot tissue is more susceptible to the initiation, development, and spread of infection than are slow-growing or nongrowing tissues.

A

B

Plate 7

A. Severe fruit blight on thornless blackberry without spread into fruit stem. (Original photo, courtesy S.M. Ries, University of Illinois, Urbana.)

B. Fire blight in red raspberry showing distinct leaf necrosis with discoloration along the veins. (Original photo, courtesy S.N. Jeffers, University of Wisconsin, Madison.)

Table 6. Relative fire blight resistance of the most common species and some varieties of rosaceous ornamental plants

Host	Most	Moderately	Least
Cotoneaster	*C. amoenus* *C. adpressus* *C. canadensis* *C. dammeri var. radicans* *C. horizontalis* *C. microphyllus* *C. praecox* *C. zabelii*	*C. apiculatus* *C. divaricatus* *C. foveolatus* *C. integerrimus* *C. nitens* *C. salicifolius* Parkteppich *C. sternianus* *C. watereri hybr.* Pendulus	*C. bullatus* *C. dielsianus* *C. franchetii* *C. hupehensis* *C. lacteus* *C. lucidus* *C. multiflorus* *C. racemiflorus* *C. reticulatus* *C. salicifolius* Herbstfeuer *C. simonsii* *C. watereri hybr.* Cornubia
Crataegus (hawthorn)	*C. arnoldiana* *C. coccinea* *C. crus-galli* *C. douglasii* *C. phaenopyrum* *C. prunifolia* *C. punctata* Ohio Pioneer *C. viridis* Winter King	*C. lavallei carrierei*	*C. alemanniensis* *C. monogyna* *C. oxyacantha* *C. pentagyana*
Pyracantha (firethorn)	*P. hybrids* Mohave Navaho Shawnee Teton	*P. coccinea* *P. rogersiana*	*P. angustifolia* *P. atalantioides* *P.* hybrid Orange Glow *P. koidzumii*
Sorbus (mountainash)	*S. aucuparia* *S. intermedia*		*S. aria*
Photinia			*P. davidiana*

Erwinia amylovora affects younger plant tissues more severely than older ones. Thus, the age of the wood into which fire blight lesions extend has been used as a criterion to judge the relative susceptibilities of host genotypes. Also, the danger of severe losses from fire blight is greater in a young orchard than in older plantings of the same variety. This relationship has become more important because the mean age of pome-fruit plantings has declined during the past two decades. In most areas of the world, and especially in Europe and North America, growers are replacing old, low-density orchards with higher density orchards, so the trees are younger, smaller, and more compact than those in older plantings.

Soil Conditions and Tree Nutrition

Soil conditions (soil type, moisture content, acidity (pH), and nutrient content), greatly affect tree growth and tree susceptibility to fire blight. Many cases of severe fire blight have occurred in orchards located on soils particularly conducive to disease development. Such soils are usually characterized as heavy (high clay content), poorly drained, highly acid, and excessively fertilized.[9]

Pear trees growing on poorly drained sites that are highly acid and low in potassium show more fire blight than comparable trees growing on well-drained soils and containing higher potassium levels. The major nutrients especially should be applied at rates necessary to maintain a good balance, because imbalances tend to increase the severity of fire blight.[15] The desired levels of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and five minor elements for bearing and nonbearing apples and pears as determined by leaf analysis are listed on the following page.

Desired levels of major and minor elements in pome-fruit leaves collected in late August

Element	Desired level[1]
Nitrogen	(A) 2.4 - 2.6%
	(B) 2.2 - 2.4%
	(C) 1.8 - 2.2%
	(D) 2.2 - 2.4%
Phosphorus	0.13 - 0.33%
Potassium	1.35 - 1.85%
Calcium	1.3 - 2.0%
Magnesium	0.35 - 0.50%
Boron	35 - 50 ppm
Zinc	35 - 50 ppm
Copper	7 - 12 ppm
Manganese	50 - 150 ppm
Iron	50+ ppm

[1]The desired level of nitrogen depends on the age, variety, intended use, and fruitfulness of the trees in question as follows:

A. Young nonbearing apples and pears.
B. Young bearing apples and pears.
C. Mature soft apples (McIntosh, Cortland, Macoun, and Golden Delicious varieties).
D. Mature hard apples (those varieties not considered soft) and those grown for processing.

Based on recommendations by Stiles and Reid [27], Cornell University, Ithaca, NY 14853.

Heavy applications of nitrogen fertilizer, sources of nitrogen fertilizer, and sources of organic nitrogen, like barnyard manure, should be avoided. Nitrogen from organic materials applied to orchards in cooler areas stimulate the development of succulent tissues late in the growing season. The application of high levels of potassium decreases the concentrations of calcium and magnesium in leaves and has the effect of withholding these two elements. Research has indicated that trees with high levels of leaf calcium and magnesium are more resistant to fire blight.

Cultural Practices

Cultivation may affect the development of fire blight through its effects on the availability of nitrogen and on tree growth. Cultivation late in the growing season should be avoided because it is likely to induce new growth, which is highly susceptible to *E. amylovora.* On some light soils in Missouri, fire blight reportedly was more severe where nitrogen-fixing cover crops (alfalfa, crown vetch) were used in the orchards. The incidence of fire blight was reduced by killing these crops and replacing them with K-31 tall fescue grass. In some locations increased incidences of fruit infections have been observed following the mowing of broadleaf cover crops between tree rows near harvest time. Inoculation of fruit by puncturing insects that migrate from such crops have been observed and recorded.

Severe pruning tends to stimulate highly susceptible succulent growth. In contrast, frequent (preferably annual), light pruning is less stimulatory than heavier pruning. Pruning done just before or during bloom may result in the inoculation of pruning wounds with *E. amylovora.*

Several reports from Michigan, Oregon, and California have indicated that increased humidity due to over-the-tree sprinkler irrigation causes greater severity of shoot blight in pear. In Ohio, significantly more twig blight was recorded in small Golden Delicious trees that were misted than in adjacent, nonmisted trees. During bloom, high humidity can increase the chance for heavy dew and blossom infection. Trees in low-lying areas of the orchard are often the most severely infected.

The fire blight pathogen may be spread during orchard establishment and maintenance. Contaminated pruning tools that are not properly decontaminated between cuts are important means of spreading bacteria from blighted to healthy branches. The organism may also be spread by hands, clothing, shoes, and the wheels of orchard equipment that have been in contact with *E. amylovora.* Contaminated budwood, especially from trees with a history of fire blight, has long been suspected to have been responsible for introducing fire blight to previously disease-free areas. When nursery stock is cut off in the spring above the dormant bud, pruning tools can easily become infested from one infected tree and thus transmit the bacterium to numerous other trees in the nursery.[26]

The use of metal limb spreaders with sharply pointed ends has been shown to help initiate fire blight infection in scaffold limbs of the resistant Seckel pear variety (pl. 7, C). Such initiation can easily be avoided by using noninjurious limb spreaders. The application of growth regulators reportedly has increased the amount of secondary blossom infection in certain pear varieties, resulting in death of the trees.

C

Plate 7

C. Severe natural infection of fire blight in scaffold limbs and central trunk of Seckel pear tree, following placement of metal limb spreaders with sharply pointed ends.

The Pathogen

Erwinia amylovora is a microorganism with only one form—the vegetative single cell (fig. 6). However, the bacterium is often found in a watery polysaccharide matrix, called ooze. Depending on weather conditions, the ooze may take on several forms. The most common and easiest to observe is the liquid form. The bacterium also may exist in threadlike strands[13] arising from stems or fruit (pl. 1, G; pl. 2, C, D and E). *Erwinia amylovora* frequently colonizes the surface of the stigma, the female part of the flower (fig. 4). The pathogen has been found in lower numbers as an epiphyte on leaf and bud surfaces[3] and as an endophyte in apparently healthy parenchyma tissues[12,21] of the vascular system (fig. 5). However, to what extent the endophytic form of the bacterium is present throughout a tree is not well known. In culture on an artificial yeast-dextrose medium, the bacterium produces characteristic small, round, glistening colonies (fig. 7).

The development of fire blight depends on the presence of sufficient numbers of the pathogen to cause infection. In areas where the disease is endemic and occurs regularly, inoculum for new infections is usually produced in holdover

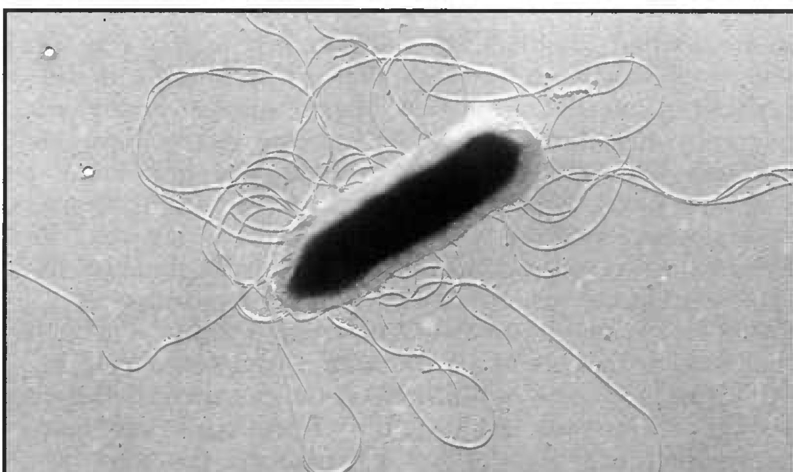


Figure 6. Single cell of *Erwinia amylovora,* with numerous peritrichous flagella (X 18,000). (Original photo, courtesy R.N. Goodman, University of Missouri.)

Figure 7. Characteristic glistening colonies of *Erwinia amylovora* on a nutrient-yeast-dextrose agar medium.

cankers from infections active during the previous growing season. In such areas, the numbers of new infections often are related to the number and activity of holdover cankers that are present in or near the orchard. Sources of inoculum other than oozing cankers are described in the disease cycle section.

In areas where fire blight does not occur regularly, new infections depend on inoculum that is introduced into the orchard by infected or infested nursery stock as endophytic or epiphytic bacteria, respectively, or by insect vectors. The pathogen may be disseminated over long distances to areas that have never had fire blight; under favorable environmental and host conditions, the disease may become established. Fire blight was well established (9 years) in England before it was noted in the western coastal areas of the European Continent, some hundreds of kilometers distant. It is likely that wind or bird vectors (or both) of *E. amylovora* enabled fire blight to become established on the continent in the mid 1960's. The amount of infection that develops in new areas depends strongly both on the circumstances that affect local dissemination of the pathogen and on weather conditions.

The Environment

Weather

Weather greatly affects the development of fire blight. Temperature, upon which the growth and multiplication of the pathogen are dependent, often determines whether or not the disease occurs and the extent of losses from disease. Free moisture in the form of rain, dew, or high relative humidity also affects the multiplication of *E. amylovora*. Weather conditions affect the development of host plants and influence their susceptibility to fire blight.

Multiplication of *E. amylovora* occurs most rapidly between 24° and 29°C (75° and 84°F). However, the pathogen can grow over a much wider temperature range of 4°-32°C (39°-90°F). The disease has occurred when temperatures did not exceed 19°C (66°F) and some infections have been observed in orchards in which temperatures did not exceed 13°C (55°F) during the critical blossoming period. Warm (>25°C or >77°F), moist conditions induce rapid growth of tissues that are highly susceptible.

Rain is promotive in the development and dissemination of fire blight. A cone shaped area of downward infections in a tree has often been reported when an inoculum source was present in the upper part of the tree. Generally speaking, fire blight is more severe in regions, such as the Northeast and Midwest, that are routinely rainy during the early parts of the growing season and hot and humid soon after. In areas where the growing seasons are usually rain free, like the Northwest, fire blight is less severe. However, in the occasional season when rain does fall during bloom, catastrophic damage can occur.

Tissue injury caused by meteorological events plays an important role in the infection process.(29) Severe outbreaks of fire blight often follow hailstorms, especially those that occur later in the growing season in orchards with infections initiated earlier. Wounds made by hailstones are ideal sites for entry of the pathogen. The rains that invariably accompany hail carry the bacteria to the wounds. Strong winds can also cause injury by whipping the leaves, the injury then allowing bacterial entry. Severe blossom blight, even of resistant apple varieties like Delicious, has been reported. It occurs when a late-spring killing frost during bloom results in numerous small wounds, which allow the bacterium to enter. Today this symptom is referred to as "trauma blight" (see MARYBLYT prediction model). Prolonged periods of rain and high moisture levels are conducive to the development of infection. Under such conditions, the pathogen may enter plant parts through unwounded yet water-soaked tissues.

Maintaining good control of insect populations will reduce the spread and incidence of fire blight.

The combination of high atmospheric humidity and abundant soil moisture raises the intercellular humidity of plant tissue and thereby enhances the multiplication rate and survivability of *E. amylovora.*[22] High atmospheric relative humidity also favors multiplication of the fire blight pathogen. Orchards have become blighted in the absence of rainfall but under conditions of high (>70 percent) relative humidity, dew, or fog. Even in areas with limited rainfall, enough surface moisture may be present on plant tissue to foster development of the disease.

Many observers have noted that fire blight seems to spread in the direction of prevailing winds. In Iowa, a definite relationship was observed between the severity of blight epiphytotics in nursery rows and the exposure of pear trees to prevailing southerly winds. Spread of fire blight was sharply reduced through the use of wind barriers. Similar observations relating the development of fire blight to the direction of prevailing winds have been made in England, France, Denmark, and The Netherlands. With wind dissemination, the organism is usually carried in drops of dew or rain. However, bacterial strands also can be blown long distances by winds. Strands have been reported in apple orchards in Illinois and Utah (pl. 2, D), on pear in Washington (pl. 2, E), and on hawthorn in Great Britain.[30]

Insects

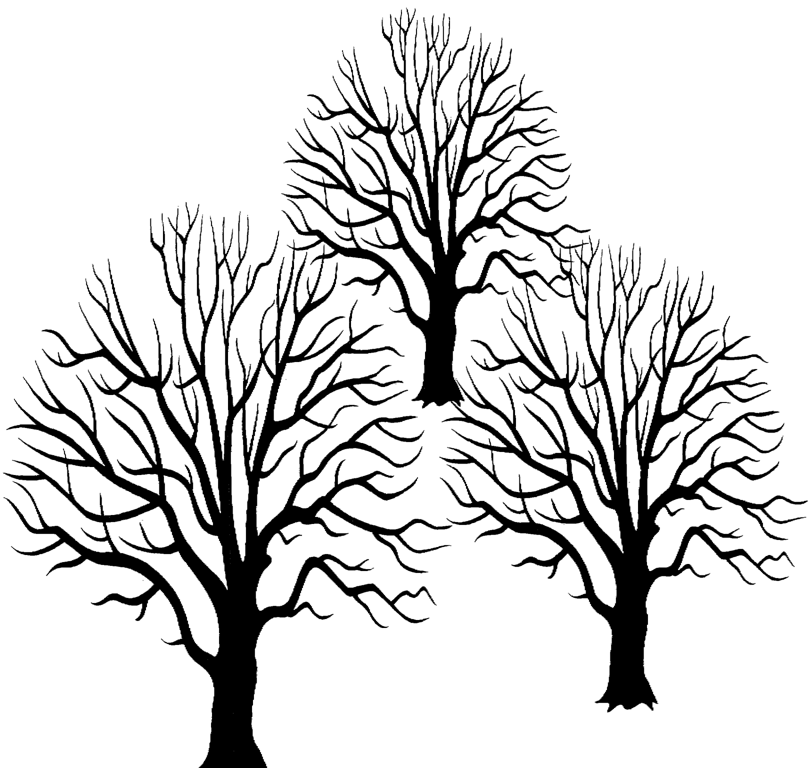
Insects probably play the most important role in disseminating *E. amylovora*. Certain insects play dual roles in the development of fire blight: they carry the pathogen on their bodies and, through their feeding activities, create infection courts for the bacteria. All major insects that have frequently been associated with fire blight[30] are listed below.

List of major insects implicated in the dissemination of *Erwinia amylovora*

Common name	Scientific name
Ambrosia beetle	*Xylosandrus germanus* (Blfd.)
Ant	*Formica* sp.
Apple aphid	*Aphis pomi* DeGeer
Honey bee	*Apis mellifera* L.
House fly	*Musca domestica* L.
Mirid	*Campyloma verbasci* (Meyer)
	Melanotrichus falvosparus (Sahlb.)
	Plagiognathus politus Uhler
Pear psylla	*Cacopsylla pyricola* Foerst.
Potato leafhopper	*Empoasca fabae* (Harris)
Rapid plant bug	*Adelphocoris rapidus* (Say)
Shothole borer	*Scolytus rugulosus* (Müller)
White apple leafhopper	*Typhlocyba pomaria* McAtee
Woolly apple aphid	*Eriosoma lanigerum* (Hausm.)

In early spring, flies, wasps, ants, and other crawling insects often contact or feed on ooze and become contaminated with *E. amylovora* (pl. 3, B). Contaminated insects may then carry the pathogen to natural infection courts. Bees, which are essential for pollinating pome fruits in temperate regions, are undoubtedly the most important disseminating agents of *E. amylovora*. They transfer bacteria from flower to flower with amazing efficiency. Studies with caged trees have demonstrated the capacity of single bees to disseminate *E. amylovora* from one blossom to virtually all blossoms of the tree. Sucking insects, particularly aphids, plant bugs, leafhoppers, and pear psylla, are instrumental in initiating the infection of vegetative shoots.[26] They create wounds that facilitate entry of fire blight bacteria into the host, and they may carry bacteria from an infected shoot to uninfected shoots.

Following all orchard management practices recommended here and by your local county Extension Service will reduce damage by fire blight.



Control Measures

Control measures to reduce the incidence and severity of fire blight are based on our knowledge of the disease cycle and the many factors affecting disease development.[5,11,28,31] The best approach to effecting disease control is to interfere with one or more of the three factors affecting fire blight development—the host, the pathogen, and the environment (including insects)—or with their interactions as discussed earlier. Unfortunately, no one procedure will completely control fire blight. The best control is attained through an integrated program of sound orchard management practices, including a serious schedule of judicious and well-timed applications of chemical control agents, against both the pathogen and its insect carriers.

Orchard Management Practices

Choosing Orchard Site and Varieties

Even before a pear or apple orchard is planted or replanted, the threat of fire blight should be considered. The potential site should be evaluated in light of the effects of soil type, drainage, and soil acidity (pH) on disease severity. The relative susceptibilities of potential rootstock, interstem, and scion varieties should be given high priority (tables 1-3). If highly susceptible genotypes are selected, growers should expect to devote considerable attention to fire blight throughout the life of the orchard. The most risky combination involves susceptible genotypes grown on sites especially conducive to severe damage from fire blight.

Most of the more severe fire blight problems have occurred in orchards planted on poor sites. These sites can be characterized as having heavy, poorly drained, and/or highly acid soils. Often such soils are chosen for pear plantings because pears will survive, whereas other fruit trees such as peaches and cherries will not. Although they survive, pears do not do well, and the poor soil makes them highly susceptible to fire blight. Planting trees on poor soil invites fire blight damage and poor fruit productivity.

Fertilization and Cultivation

The fertilization program should be designed to 1) discourage late vegetative shoot growth and 2) provide the proper balance of the major nutrients and especially avoid an excess of nitrogen. Attention should be given to soil conditions. Lime should be applied to correct excess acidity, and, if necessary, drainage should be improved by installing tiles or plastic drain tubing.

Although nutrients are usually applied in early spring, nitrogen applications can be split. One-half the required amount can be applied to the soil at least 1 month before growth starts. If blossom infection is not serious, the other half can be applied as foliar or ground sprays after petal fall. Foliar sprays of urea are more effective on apple than pear in making foliage green. Ground sprays of soluble nitrogen compounds can be used on either crop. If severe fire blight should develop, later planned applications should be withheld. On less well-drained soils, the nitrate form of nitrogen is preferred, because of its immediate total availability. Calcium nitrate is probably best, since the calcium will tend to increase fire blight resistance.

Late cultivation should be avoided because it encourages late growth by making more nitrogen available to trees. The cover crop should be well mowed early in the season and then allowed to grow in midsummer to check tree growth. Grass sod is preferred as a cover crop because legumes, like alfalfa or clover, usually offer too much competition to tree growth and make control of available nitrogen more difficult.

Pruning and Removal of Risky Structures

It is best to prune orchards frequently, annually if possible. With frequent pruning, only small cuts are necessary. Larger cuts encourage the development of many highly susceptible suckers. In addition, annual pruning improves the chances of removing fire blight cankers and, in general, better controlling the disease.

Removing root suckers and rootstock sprouts is risky because, if the wounds become infected, whole trees may be killed. During the dormant season, root sprouts and suckers should be cut off a short distance above the soil line. In the following year, new sprouts will arise from year-old tissue. These should then be cut off above the first cut. If this practice is continued for several years, a more blight-resistant structure will gradually develop. During the growing season, application of contact herbicides to vigorously growing root suckers and rootstock sprouts will reduce the likelihood of their infection by fire blight.

Summer pruning is becoming a more common practice in high-density apple plantings. It is often done to increase fruiting wood; thus, it deliberately encourages new shoot growth and thereby extends the period for shoot blight susceptibility. Any operation, such as summer pruning, that produces wounds on soft, succulent tissue must be conducted with caution. If fire blight is present, summer pruning should be done only with disinfested tools and during dry weather. Caution is needed especially for susceptible varieties. Pruning should be avoided entirely in orchards that are severely affected by fire blight. If entire blocks are severely blighted, growers need to decide whether to replant the blocks or try to bring infected trees back into production.

Spurs that occur on the trunk and scaffold limbs of standard-size apple and pear trees should be removed to eliminate the possibility of their becoming infected. Infection of trunk and scaffold spurs may result in complete girdling of the supporting structure and lead to loss of significant portions of trees. The few fruit that would be borne on such spurs are not worth the risk of losing large limbs and are unlikely to be well colored in any case.

Early fruiting should be encouraged, not only because fruit production will be greater but also because succulent vegetative growth and, therefore, susceptibility to damage by fire blight will be reduced. But growers should be aware that the earlier the tree blooms, the greater the risk of infection.

Reducing Bacterial Inoculum Levels

Because *E. amylovora* commonly overwinters in cankers, as many cankers (and dead tissue) as practical should be removed during the dormant season. Cuts should be made well into healthy tissue to ensure that all infected tissue is removed. Early season sprays of bordeaux mixture plus oil (discussed below) have been shown to reduce surface inoculum from cankers that may have been overlooked. Prompt removal of early season infections reduces the inoculum available for initiating secondary infection and prevents severe loss of tree structure.

Removal of Overwintering Cankers

Canker removal can be accomplished either by complete removal of the affected tree or tree parts or by surgical treatment. Removal is most easily accomplished in late winter at the same time that trees are pruned. In the Eastern United States, the danger of cold injury and the spread of *E. amylovora* is least between January 15 and March 15. The most critical cankers to be removed occur on the larger tree structures of the more susceptible varieties. These cankers generally have smoother margins and a greater likelihood of becoming active in the spring.

If pruning is done during the dormant period, it is advisable to disinfest tools. However, if fire blight pruning is done any other time, pruning tools **must** be disinfested between each cut. Tools should be dipped in or swabbed with denatured methyl alcohol, which is obtainable cheaply as shellac thinner. A 70-percent solution, made by mixing three volumes of denatured alcohol with one volume of water, is most effective.[6] A 10-percent solution of liquid laundry bleach (active ingredient, sodium hypochlorite) can also be used. This preparation is the more effective but is corrosive to most pruning tools. If it is used, the tools should be thoroughly rinsed, dried, and oiled at the end of each day.

Figure 8. Steps in treatment of trunk with fire blight canker at base of twig. Left, twig is cut off flush with the surface of the trunk. Right, cankered bark and narrow band of adjacent, healthy bark are scraped off; scraped area (wound) is shaped as a pointed oval whose long axis aligns with that of the trunk; wound is thoroughly disinfested with alcohol or sodium hypochlorite and then covered with tree paint or wound dressing. (From C.R. Drake, 1976. "Fire Blight of Apple and Pear and Its Control in Virginia." Virginia Polytechnic Institute, Extension Bulletin No. 35. Original photo, courtesy C. R. Drake.)

Certain cankers are best removed by scraping. This operation is recommended only for those cankers that do not encompass more than half the circumference of larger branches and trunks. Such cankers are most likely to occur where a blighted spur or branch meets a larger branch. To remove the canker, first cut off the blighted spur or branch flush with the larger branch. Then scrape away all the bark in the canker area and the healthy bark for a distance of at least 2 cm (0.8 inch) from the canker margin. Use a pruning knife, farrier's hoof knife, or similar tool with a curved blade. The cut area should form a pointed oval oriented with the longitudinal axis of the limb. Reference to figure 8 should assist in understanding the procedure. The bark should be cut as nearly perpendicular to the branch as possible to encourage rapid formation of callus. Finally, the wound should be swabbed with 70 percent alcohol or 10 percent liquid laundry bleach; the treated area may be covered with a commercial wound dressing. If a large proportion of the circumference of the bark is removed, bridge grafts will speed healing.

Recent studies in Maryland have indicated a relationship between orchard temperature and the activity of holdover cankers.[24] Systemic canker activity begins with the accumulation of at least 72 degree-days (DD's) above 12.7°C (130 DD's above 55°F) after the green tip stage of blossom bud development. One degree-day equals the average daily temperature 1 degree above 12.7°C. Canker extension can be seen regularly at 122 DD's above 12.7°C (220 DD's above 55°F) after the green tip stage. External symptoms (canker blight) result from internal movement of the pathogen into limbs and shoots adjacent to active canker sites (see MARYBLYT prediction model).

Control of Nonorchard Sources of Inoculum

Several ornamental species are frequently attacked by fire blight. These plants may produce inoculum that will infect orchard trees. Many species of hawthorn *(Crataegus)*, firethorn *(Pyracantha)*, mountainash *(Sorbus)*, *Cotoneaster*, and *Photinia*, as well as ornamental apples, pears, and quince, are susceptible. Plants of these species should be watched closely or, if possible, be eliminated from the vicinity of commercial apple or pear orchards. Because of differences in bloom time, weather conditions may favor the infection of these hosts more than orchard apple or pear. Subsequently, these infected shrubs and trees may provide massive amounts of inoculum that will infect orchard trees.

Eradication of Early Blossom Infection

Pruning of blighted blossom clusters and vegetative shoots in the spring and summer should be done carefully to avoid initiating new infections in susceptible tissues. During periods of active lesion extension, pruning cuts should be made 15-30 cm (6-12 inches) or more below visible lesions, because bacteria are present in tissues that do not yet appear to be symptomatic.

Orchards should be inspected 10-14 days after bloom for the presence of new blossom infections. All infected spurs should be cut off at least 15 cm (6 inches) below the farthest evidence of infection. It is best to remove infections as early as possible. Cutting tools used for the removal must be disinfested as described to prevent transfer of the pathogen.

Alternatively, infected branches can be broken off by hand well below the farthest extent of infection. Monitoring should be repeated twice weekly for several weeks. If many new infections are found, an active holdover canker should be sought in the vicinity and be removed. Removal of the source canker and new blossom infections prevents, as much as possible, the secondary spread of infection to the terminal growth by reducing the amount of inoculum available.

Preventing Disease Development in the Host

If the fire blight pathogen and its hosts do not come together or if they come together under conditions that are unfavorable for development of the pathogen, no disease can occur. There are several things that growers can do to prevent or discourage the establishment of the pathogen on the host. Insect vectors of *E. amylovora* can be controlled to reduce the potential for both the spread of the pathogen and inoculation of host plants. The host environment can be treated chemically to inhibit bacterial multiplication. The most efficient way to control fire blight is to take appropriate actions in response to reliable prediction as to when blossom and shoot blight is likely to occur.

Predicting the Occurrence of Fire Blight

The incidence and severity of fire blight vary greatly from season to season and from orchard to orchard. Therefore, many attempts have been made to relate the sporadic occurrence of fire blight with particular weather patterns and orchard conditions.

Mills[16] and Parker et al.[17] in New York in the 1950's and Powell[18] in Illinois in the 1960's used local weather data and observations or reports of disease occurrence in many orchards in their respective regions to establish guidelines on which growers might base decisions on whether or not to apply bactericides. The Mills system was based primarily on temperature and moisture during bloom, whereas the Powell system was based both on heat units accumulated between the last freeze and early bloom as well as on temperatures during bloom. Both systems have found some application in their respective regions.

During the past 15 years, three conceptually different models were developed in the United States to help growers decide whether and when bactericides should be applied to their orchards. All relate the presence of *E. amylovora* (in the epiphytic stage) on blossoms to temperatures and other meteorological factors, and then establish thresholds above which disease can be expected to occur. When the thresholds are met, application of bactericides is indicated.

Applying well-timed chemical sprays, based on an accurate disease prediction system, is the most effective way to combat fire blight.

The Mean Temperature Line. In the early 1970's, in California, Thomson et al.[28] developed a model which is based on the relation between occurrence of epiphytic bacteria in pear blossoms and average daily orchard temperatures. Previously, *E. amylovora* was considered to be present in the orchard whenever blossoms were open; thus, recommendations for bactericide application had been based primarily on the presence of blossoms. Consequently, application began with the first open blossoms and continued on a regular schedule, which often resulted in 15 applications per season. Epiphytic *E. amylovora* were first found during bloom when the average daily temperature exceeded the temperatures that fall on a line drawn from 16.7°C (62°F) on 1 March to 14.4°C (58°F) on 1 May as shown in figure 9. Using this model, routine application of bactericides is delayed until the first day that the average temperature exceeds the temperature on this prediction line for the corresponding day. Once application of bactericides begins, a schedule is followed as long as blossoms are present in the orchard. During the past decade, this model has been applied quite effectively in Utah to predict and control blossom blight on apples.

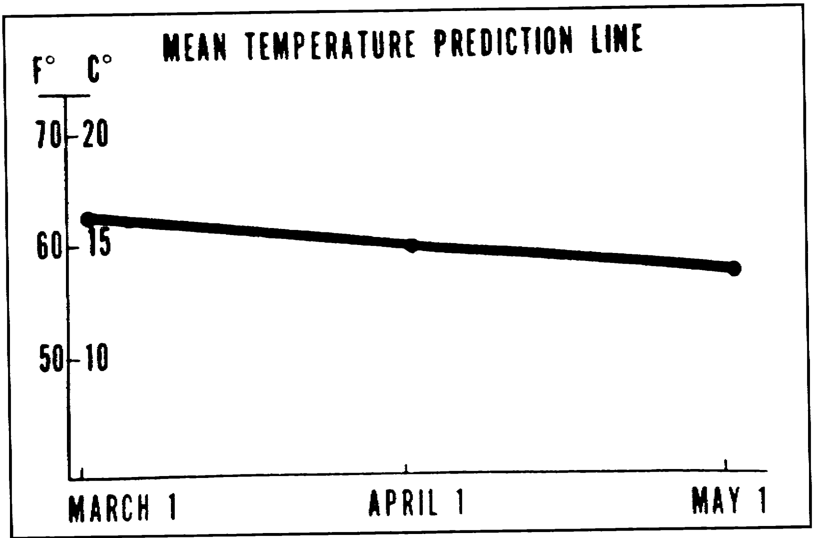


Figure 9. Mean temperature line between March 1 and May 1, used to predict blossom blight in Utah and northern California. (From Thomson et al. (28). Reprinted by permission.)

The Degree-Hour System. In the mid 1970's, also in California, Zoller and Sisevich[33] determined that the incidence of epiphytic bacteria on pear flowers was related to the accumulated numbers of degree-hours (DH's) above 18.3°C (65°F). One C-degree-hour equals 1 degree above 18.3°C for 1 hour; 56 C-degree-hours equals 100 F-degree-hours. When 3 consecutive days below 18.3°C occur, the accumulated number of degree-hours is reduced to zero. A total of about 150 cumulated degree hours (CDH's) is the signal that the first bactericide application is to be made just prior to the next rainfall (fig. 10). From 1976 to 1987 in the Sacramento Valley of California, the random occurrences of new infections correlated highly with seasonal degree-hours above 18.3°C and also with the incidence of rains that were accompanied by high relative humidities and temperatures equal to or greater than 13.9°C (57°F). During the past 10-12 years, this system has been used with a high degree of success on 35 percent of the Bartlett pear acreage in California's Sacramento River Delta, 50 percent of the acreage in Mendocino County, and 70 percent of the acreage in Lake County. A detailed comparison between these two American systems and disease observations in West Virginia has been published.[31]

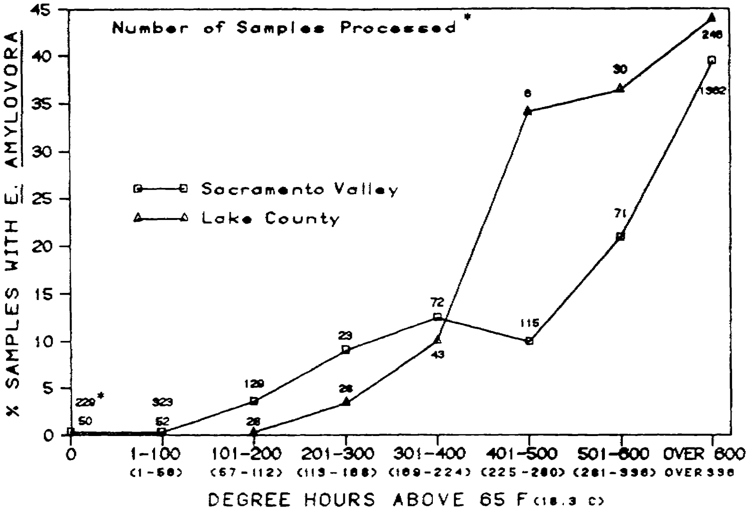
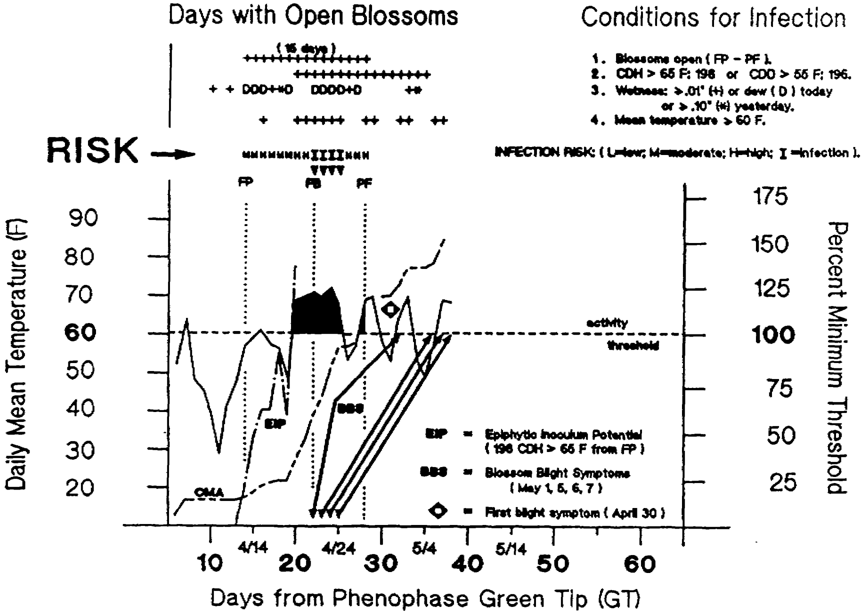


Figure 10. Percentage of blossom samples colonized by *Erwinia amylovora* vs. degree hours above 18.3°C (65°F) since last 3-day period with no temperature above 18.3°C (1972-76). (From van der Zwet et al. [31]).

The MARYBLYT Model. In 1987, in Maryland, Steiner [23, 24] developed MARYBLYT, a comprehensive model for fire blight management. The model is partly based on the previously mentioned systems. MARYBLYT identifies the conditions that are conducive to the development of four separate types of fire blight symptoms, identifies infection events, and predicts symptom development. The four types of symptoms are associated with blossom, canker, shoot, and trauma blight.

For **blossom blight**, the minimum conditions for infection by *E. amylovora* are 1) blossom must be open with stigmas and petals intact, 2) passage of at least 110 CDH's above 18.3°C (198 CDH's above 65°F) from first open bloom, 3) a wetting event equal to or more than 0.25 mm (0.01 inch) of rain or a heavy dew or fog (sufficient to wet foliage) or a rain equal to or more than 2.5 mm (0.10 inch) the previous day, and 4) an average daily temperature of 15.6°C (60°F). Infection will occur when *E. amylovora* is present and all of the above conditions develop in the sequence given. Blossom blight symptoms (BBS) will appear upon passage of 57 cumulated degree days (CDD's) above 12.7°C (103 CDD's above 55°F) from the date of infection (fig. 11). This period can vary from 5 to 30 calendar days depending on the prevailing temperatures. Because each of the four basic conditions for blossom infections can be predicted, treatments with bactericides can be scheduled for the day before or the day of infection and are very effective.

Severe Blossom Blight 1985



No Blossom Blight 1991

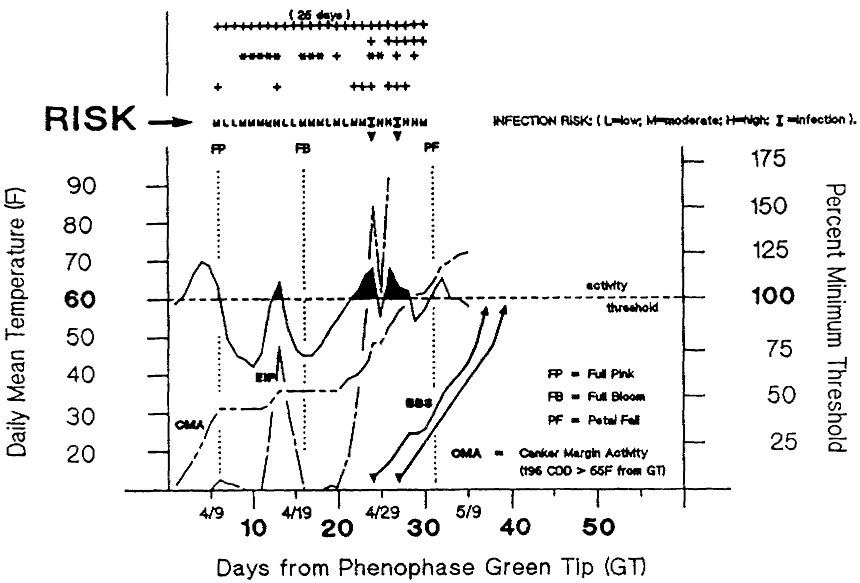


Figure 11. Schematic presentation of MARYBLYT prediction system, showing a comparison between a severe blossom blight year (1985) and a season without any blossom blight (1991) at the Appalachian Fruit Research Station in West Virginia.

Canker blight involves renewed infection activity by the pathogen at the margins of overwintering cankers during the early prebloom period. The first symptoms appear as a water soaked zone in the green bark at canker margins. This canker margin activity (CMA) occurs with the accumulation of 109 DD's above 12.7°C (196 DD's above 55°F) after the green tip (GT) stage of bud development. Canker blight symptoms (CBS) on nearby shoots (through internal invasion) then become evident after 166 CDD's above 12.7°C (299 CDD's above 55°F). The 57 CDD's greater than 12.7°C interval between CMA and CBS is similar to the blossom infection-to-symptom (BBS) interval mentioned under blossom blight.

Shoot blight is limited to direct infection of vegetative shoot tips and occurs when 1) blossom or canker blight symptoms develop, 2) insect vectors with sucking or piercing mouth parts become available, and 3) the daily temperature is 15.6°C (60°F) or above. The fourth fire blight symptom, **trauma blight,** is unusual and affects many different tissues injured by late frosts (<-2°C or <28°F) or hail or high winds that damage the blossoms or foliage. The MARYBLYT Version 4 model[25] is currently being evaluated in fruit growing areas throughout the United States and in several foreign countries.

Chemical Control

Chemicals (bactericides) can interfere with the development of fire blight during three distinct growth periods of the host: 1) dormant, 2) bloom, and 3) postbloom. Bactericides used to control fire blight reduce inoculum survival in early spring or inhibit the multiplication of *E. amylovora* and thus help prevent the development of new infections in blossoms or shoots.

The chemicals available to inhibit the development of fire blight are limited in efficacy and in number, especially relative to the pesticides available to control insects, weeds, and fungi. There are two categories of bactericides: copper compounds and antibiotics. The efficacy of copper compounds is generally not as great as that of the antibiotics in controlling blossom blight.

Notice on the Use of Chemicals

The use of pesticides, including bactericides, in orchards, in nurseries, and on landscape plants is strictly regulated by various government agencies in almost all regions of the world. Regulations often specify the materials and their concentrations that can be used; the time, mode, and frequency of application; and the qualifications of personnel authorized to possess and use pesticides. The information presented is based on experience with materials that have been used in some regions to influence the development of fire blight. Whether these materials can be used must be determined by consultation with appropriate authorities having jurisdiction for pesticide use in the particular region of concern. The recommendations presented in this section are not to be construed as endorsed by the authors, Cornell University, or the United States Department of Agriculture.

Copper compounds were the first chemicals used for fire blight control. A variety of compounds and formulations are available, including a mixture of copper hydroxide and sulfur (Kocide 101), copper oxychloride sulfate (COCS), various other inorganic and also some organic copper compounds. The classic bordeaux mixture, described below, has been used extensively. As a group, copper compounds are less effective in controlling fire blight and are more phytotoxic than antibiotics. Most copper compounds cause leaf chlorosis or necrosis and fruit russetting when applied to pear or apple orchards; severity depends on the compound used, timing with respect to stage of growth, formulation and concentration used, and the variety of trees treated.

Antibiotics are antimicrobial compounds that are produced by other microbes. They are produced in quantity either by growth of the organism that synthesizes them or through chemical synthesis. Some have questioned the advisability of using antibiotics for plant protection, because the same materials are sometimes used in human and animal medicine. Widespread use of antibiotics may lead to the development of bacteria that are resistant to the antibiotics; conceivably that resistance may be transferred to bacteria of medical importance.

Streptomycin (Agri-Strep, Agrimycin) is the most effective material available for fire blight control. It limits bacterial multiplication; but because it is only locally systemic, it is not effective when applied to unopened blossoms. Agri-Strep is generally applied at 50-100 ppm, i.e., 113-227 g/378 L (4-8 oz/100 gal) as a dilute spray. For increased streptomycin efficacy, consideration should be given to adding a wetting agent, such as Regulaid, to the spray or to making the spray applications during early evening or night. Application under poor drying conditions aids absorption.

In some apple and pear orchards in the West and Midwest, strains of *E. amylovora* that are resistant to streptomycin have been recovered. In these orchards, the antibiotic is ineffective, and oxytetracycline or copper compounds must be used to control fire blight. Oxytetracycline (Terramycin), recommended at 200 ppm, is effective against the streptomcyin-resistant strains, but it is generally less effective than streptomycin against streptomycin-sensitive strains of *E. amylovora*. Kasugamycin is a third antibiotic used for fire blight control in some countries.

Dormant Season. In pear and apple orchards that had been severely affected by fire blight during the previous growing season, sprays of high concentrations of bordeaux mixture (copper sulfate-hydrated lime-water) plus oil or of copper hydroxide plus oil have been shown to inhibit or delay the production of inoculum by holdover cankers. Sprays of 8-8-100 bordeaux mixture plus 1 percent of 60- or 70-second emulsifiable spray oil or sprays of 2-4 pounds of copper hydroxide or COCS per 100 gallons plus oil should be applied to runoff (2,500 L/ha or 320 gal/acre) after the swollen bud stage but before the bud burst stage (green tip to 6 mm (quarter inch) green) of bloom development. Copper compounds are severely phytotoxic if applied later in the growing season. Dormant oil treatments are also effective because they reduce the populations of crawling insects, viable insect eggs, and mites, which are instrumental in the spead of fire blight.

Preparation of Bordeaux Mixture

First dissolve 3.6 kg (8 lb) crystalline copper sulfate in 378 L (100 gal) of water in the spray tank. After the copper sulfate is dissolved, add 3.6 kg (8 lb) hydrated spray lime (350 mesh), either mixed in water or as powder, to the tank. Constant agitation is needed to thoroughly mix the contents of the tank. Finally, add 3.8 L (1.0 gal) of spray oil.

Bloom Season. Blossoms of all apple and pear varieties are susceptible to infection. When mean temperatures rise above 18.3°C (65°F), especially in combination with rainfall or 60 percent or higher relative humidity, protective sprays should be applied. The several predictive systems mentioned above may be used to help the horticulturist decide when to apply bactericides to control fire blight. If a prediction system is not used, bactericides should be applied at 5-day intervals or at 5 percent bloom, 50 percent bloom, and full bloom. Even though the flowers pass through these stages rather quickly in some areas and in some seasons, an attempt should be made to apply the blossom treatments at each stage, because freshly opened blossoms are extremely susceptible and available materials are not effective when applied to unopened blossoms.

Recommendations for spraying during bloom differ in the different geographical areas. Therefore, growers are advised to consult their local Cooperative Extension Service (or other advisory service) for current information of registered materials and specific control recommendations. Antibiotics and copper compounds have little systemic or eradicative action and therefore must be applied before infection occurs. Thus, several applications must be made at regular intervals to ensure protection during the bloom period. Mild bordeaux mixtures (2-6-100 or 3-3-100) reportedly have been quite effective for blossom blight control. However, under some weather conditions, the concentrations needed for control may cause blossom, leaf, and fruit russet.

In the East and Midwest, where the bloom period is generally short, one to four sprays per season may be needed. In these regions, several apple varieties (McIntosh, Empire, Mutsu, Gala, Golden Delicious, and spur-type Delicious) on rootstocks Mark, M.9, M.26, and MM.106 produce abundant secondary blooms. These blooms can be a major hazard in fire blight control. In the West, where secondary bloom is common on pear and chilling requirements for primary blossoms are not always met before growth resumes in the spring, as many as 15 to 20 applications may be needed.

Postbloom Season. Postbloom sprays should be applied if temperatures and humidities continue in the optimum ranges for blight development, and especially if conditions for infection during bloom have been favorable. Spray intervals can be varied from 7 to 12 days, depending on environmental conditions and varietal susceptibility. In southern Oregon, summer pears are routinely sprayed three times following bloom, winter pears four times, and apples four or five times. Because insects (such as aphids, leafhoppers, psylla, and plant bugs) and mites spread the pathogen during the growing season, it is essential to maintain good insect control while vegetative growth continues.

Whenever a severe rainstorm, windstorm, or hailstorm occurs, bactericides should be applied **within 24 hours** after the storm, or immediately after the storm, if possible.[29] Extensive shoot and fruit infection has been observed many times in orchards that did not receive a timely application of bactericides following such storms. However, growers should be aware of residue regulations, which restrict bactericide application as apple and pear harvest approaches.[14]

Limitations for Use of Antibiotics

DO NOT apply antibiotics to- [apples within 50 days / pears within 30 days] -of harvest

Severe terminal shoot blight may develop late in the season (August-September) when succulent terminal shoot growth is stimulated after wet weather follows a lengthy dry period during summer (pl. 6, A). Such growth also promotes development of the green apple aphid, which may help spread fire blight even farther. Therefore, under such weather conditions, growers are advised to apply aphicides and bactericides at recommended rates.

Control of Insect Vectors

Insects are very often important in the primary infection of blossoms early in the spring. A wide range of flying and crawling insects, including ants, flies, and wasps, may be responsible for primary inoculation. Control of these insects before bloom helps reduce insect-mediated primary inoculation. Dormant oil treatments, for instance, are somewhat effective in ridding trees of crawling insects. However, even with complete eradication of early season insects, primary inoculation may not be prevented completely because dissemination can also be accomplished by rain.

Sucking insects, particularly aphids, plant bugs, and pear psylla, are instrumental in helping to initiate vegetative shoot infections, especially in tree nurseries where large numbers of trees produce excessive succulent growth. These insects tend to feed on soft, succulent shoots, the same shoots that are highly susceptible to fire blight infection. During feeding, the insects not only create wounds that may facilitate entry of the pathogen into host tissue but may also transfer the pathogen from an infected shoot to an uninfected shoot. High populations of the white apple leafhopper have been shown to increase shoot blight, especially in the young shoots formed near blossom clusters. A higher degree of insect control is required to reduce fire blight than to prevent routine insect damage to trees.

Guidelines for Integrated Orchard Management Practices to Control Fire Blight

1. Orchard Selection and Maintenance

a. Select well drained orchard sites; if necessary, improve drainage with proper tiling and ditching.

b. Keep cover crops mowed to reduce insect populations.

c. Remove tree suckers and root sprouts.

d. Remove cankers and blighted branches from orchard trees and from ornamental trees, shrubs, and wild host plants within 800 m (one-half mile) of the orchard.

e. Prune orchards often, annually if possible, to avoid making large cuts.

f. Patrol the orchard **frequently** during bloom and early summer: remove and burn new blighted shoots; make primary cuts 45-60 cm (18-24 inches) below visible symptoms and disinfest tools after each cut with 10 percent sodium hypochlorite (household bleach) for 2-3 seconds. Rinse and oil tools at the end of each day.

2. Tree Selection and Nutrition, and Soil Management

a. Select resistant scion varieties, rootstocks, and interstems.

b. Check health status of trees through annual leaf analyses and apply nutrients to maintain desired N-P-K balance.

c. Use soil analysis as guide in applying lime, and maintain soil acidity at pH 5.5-6.5.

d. Avoid overhead irrigation and use drip irrigation where needed.

3. Control Measures

a. Keep spray equipment clean and calibrated.

b. After thoroughly pruning orchards with a recent history of fire blight, treat entire orchard with 8-8-100 bordeaux mixture plus 1 percent oil at the green tip to 6 mm (quarter inch) green stage of flower bud growth.

c. Use a hygrothermograph or a minimum-maximum thermometer and consult weather forecasts frequently, especially before and during bloom, to learn whether environmental conditions are conducive to infection. If at all possible, follow a fire blight prediction system.

d. If a prediction system is not used, apply sprays of bactericides at 5 percent, 50 percent, and full bloom or at **5-day** intervals, especially if warm, rainy, humid weather prevails during bloom.

g. Do **not** apply insecticides during bloom but maintain a **thorough** insect control program during the growing season, especially if sucking insects (aphids, psylla, white apple leafhoppers, and plant bugs) prevail.

h. When severe windstorms or rainstorms with or without hail occur, apply bactericides **within 24 hours**.

There is no total eradication or absolute cure for fire blight, but the application of all available integrated orchard management practices will keep fire blight damage to a minimum.

Key References

1. Aldwinckle, H.S., and S.V. Beer. 1979. Fire blight and its control. Horticultural Reviews 1:423-474.

2. Arthur, J.C. 1985. Proof that bacteria are the direct cause of the disease in trees known as pear blight. American Association for the Advancement of Science Proceedings 34:295-298.

3. Baldwin, C.H., and R.N. Goodman. 1963. Prevalence of *Erwinia amylovora* in apple buds as detected by phage typing. Phytopathology 53:1299-1303.

4. Beer, S.V., and J.L. Norelli. 1977. Fire blight epidemiology—factors affecting release of *Erwinia amylovora* by cankers. Phytopathology 67:1119-1125.

5. Beer, S.V., and D.C. Opgenorth. 1976. *Erwinia amylovora* on fire blight canker surfaces and blossoms in relation to disease occurrence. Phytopathology 66:317-322.

6. Beer, S.V., and J.R. Rundle. 1987. Disinfectants for treating pruning shears used for fire blight infections. Acta Horticulturae 217:243.

7. Burrill, T.J. 1980. Anthrax of fruit trees; or the so-called fire blight of pear, and twig blight of apple trees. American Association for the Advancement of Science Proceedings 29:583-597.

8. Cummins, J.N., and R.L. Norton. 1974. Apple rootstock problems and potentials. New York Food and Life Sciences Bulletin 41, 15 pp.

9. Fisher, E.G., K.G. Parker, N.S. Luepschen, and S.S. Kwong. 1959. The influence of phosphorus, potassium, mulch, and soil drainage on fruit size, yield, and firmness of the Bartlett pear and on development of the fire blight disease. American Society for Horticultural Sciences 73:78-90.

10. Goodman, R.N. 1983. Fire blight—A case study. *In* Callow, ed., Biochemical Plant Pathology, pp. 45-63, John Wiley and Sons, New York.

11. Hildebrand, E.M. 1939. Fire blight and its control. New York (Cornell) Agricultural Experiment Station Bulletin 405, 32 pp.

12. Keil, H.L., and T. van der Zwet. 1972. Recovery of *Erwinia amylovora* from symptomless stems and shoots of Jonathan apple and Bartlett pear trees. Phytopathology 62:39-42.

13. Keil, H.L., and T. van der Zwet. 1972. Aerial strands of *Erwinia amylovora:* Structure and enhanced production by pesticide oil. Phytopathology 62:335-361.

14. Keil, H.L., and R.A. Wilson. 1968. Relation of streptomycin sprays to fire blight control and apple fruit residue. Plant Disease Reporter 52:259-262.

15. Lewis, L.N., and A.L. Kenworthy. 1962. Nutritional balance as related to leaf composition and fire blight susceptibility in the Bartlett pear. American Society for Horticultural Science Proceedings 81:108-115.

16. Mills, W.D. 1955. Fire blight development on apple in western New York. Plant Disease Reporter 39:206-207.

17. Parker, K.G., E.G. Fisher, and W.D. Mills. 1956. Fire blight on pome fruits and its control. New York (Cornell) College of Agriculture Extension Bulletin 966, 23 pp.

18. Powell, D. 1965. Factors influencing the severity of fire blight infections on apple and pear. Michigan State Horticultural Society Annual Meeting 94:1-7.

19. Reimer, F.C. 1925. Blight resistance in pears and characteristics of pear species and stocks. Oregon Agricultural Experiment Station Bulletin 214, 99 pp.

20. Rosen, H.R. 1929. The life history of the fire blight pathogen, *Bacillus amylovorus,* as related to the means of overwintering and dissemination. Arkansas Agricultural Experiment Station Bulletin 244, 96 pp.

21. Rosen, H.R. 1933. Further studies on the overwintering and dissemination of the fire blight pathogen. Arkansas Agricultural Experiment Station Bulletin 283, 102 pp.

22. Shaw, L. 1935. Intercellular humidity in relation to fire blight susceptibility in apple and pear. New York (Cornell) Agricultural Experiment Station Memoir 181, 40 pp.

23. Steiner, P.W. 1989. Predicting apple blossom infections by *Erwinia amylovora* using the MARYBLYT model. Acta Horticulturae 273:139-148.

24. Steiner, P.W. 1989. Predicting canker, shoot and trauma blight phases of apple fire blight epidemics using the MARYBLYT model. Acta Horticulturae 273:149-158.

25. Steiner, P.W., and G. Lightner. 1992. MARYBLYT: a predictive program for forecasting fire blight disease in apples and pears. Version 4.0 of copyrighted computer program, University of Maryland, College Park, MD 20742.

26. Stewart, V.B. 1913. The fire blight disease in nursery stock. New York (Cornell) Agricultural Experiment Station Bulletin 329, 54 pp.

27. Stiles, W.C., and W.S. Reid. 1991. Orchard nutrition management. Cornell Cooperative Extension Information Bulletin 219, 22 pp.

28. Thomson, S.V., M.N. Schroth, W.J. Moller, and W.O. Reil. 1982. A forecasting model for fire blight of pear. Plant Disease 66:576-579.

29. van der Zwet, T., and H.L. Keil. 1972. Importance of pear tissue injury to infection by *Erwinia amylovora* and control with streptomycin. Canadian Journal of Microbiology 18:893-900.

30. van der Zwet, T., and H.L. Keil. 1979. Fire blight—A bacterial disease of rosaceous plants. U.S. Department of Agriculture, Agriculture Handbook 510, 200 pp.

31. van der Zwet, T., B.G. Zoller, and S.V. Thomson. 1988. Controlling fire blight of pear and apple by accurate prediction of the blossom blight phase. Plant Disease 72:464-472.

32. Westwood, M.N., and P.B. Lombard. 1983. Pear rootstocks: Present and future. Fruit Variety Journal 37:24-28.

33. Zoller, B.G., and J. Sisevich. 1979. Blossom populations of *Erwinia amylovora* in pear orchards vs. accumulated degree hours over 18.3 Celsius. Phytopathology 69:1050.